PRACTICAL EXERCISES

IN

HEAT

BEING A LABORATORY COURSE FOR SCHOOLS OF SCIENCE AND COLLEGES

BY

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PREFACE.

THE importance of a sound knowledge of the scientific principles upon which the numerous applications of the energy of heat are based is now fully recognised, with the result that nearly all schools of science and technology provide laboratory courses in heat, intended for students of physics, chemistry and engineering.

The practical exercises given in this book are the result of many years' experience of the actual work of arranging and organising suitable laboratory work in heat for students of different grades, who for one purpose or another require an experimental knowledge of the subject.

The elementary experiments are intended for first year students, whether of an organised school of science or of a technical institute. The more difficult exercises may be worked by second and third year students taking special courses of study in electrical and mechanical engineering, chemistry, etc. Elementary students may with advantage work in pairs, and in later exercises, where simultaneous observations must be made, the same plan should be followed with advanced students.

The apparatus required has been designed to combine accuracy with durability, and so to avoid the annoyance caused by the constant attention and repair required by inferior instruments.

Ideas for experiments have been gathered from several sources, and teachers will recognise the debt the book owes to standard works, such as Glazebrook and Shaw's *Practical Physics*, Schuster and Lees's *Intermediate* and *Advanced*

Courses of Practical Physics, Wiedemann and Ebert's *Physikalisches Praktikum*, Preston's *Heat*, Edser's *Heat*, etc.

The majority of the diagrams have been drawn by Messrs. F. J. Cunliffe and C. Johnson, engineering students of the Salford Royal Technical Institute, and some have been taken, with the author's permission, from Edser's *Heat*.

The tables at the end of the book are based upon the *Smithsonian Physical Tables* and the *Tabellen* of Landolt, Börnstein and Meyerhoffer. The mathematical tables are taken from Castle's *Practical Mathematics*.

I am glad to express my deep obligation to Dr. C. H. Lees for valuable suggestions, especially with reference to the experiments on conductivity, and to Prof. R. A. Gregory and Mr. A. T. Simmons for constant help and experienced criticism.

E. S. A. ROBSON.

SALFORD, *September*, 1902.

PREFACE TO THE SECOND EDITION.

IN the present edition the text has been thoroughly revised and important additions have been made to several sections of the book. Additional questions have been included, and should prove of great use to students preparing for Board of Education or University Examinations.

Owing to the recent redetermination of many physical and chemical constants, it has been found necessary to recast and amplify the Tables at the end of the book; in this work of revision the excellent *Physical Tables* (Longmans) compiled by Dr. G. W. C. Kaye and Prof. T. H. Laby have been consulted.

The author is indebted to several science teachers who have suggested alternative or additional experiments; mention should also be made of the valuable assistance derived from Mr. C. R. Darling's *Heat for Engineers* (Spon), and Dr. J. F. Spencer's *Experimental Course of Physical Chemistry* (Bell).

E. S. A. R.

WARRINGTON, *February*, 1913.

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CHAPTER I.

THERMOMETRY.

1. Construction of a mercury thermometer.

Apparatus.—Thermometer tube ready for filling, mercury.

(*a*) Notice that the empty thermometer tube has a cylindrical bulb D (Fig. 1) blown on it, also that the bore has a slight expansion at the upper end C, while the open end A is widened in the form of a thistle funnel.

(*b*) Partially fill A with mercury, then warm the bulb D in the flame of a Bunsen burner so as to drive out some of the contained air. Allow it to cool and note that the mercury is drawn into the bulb and will probably half fill it.

Repeat this process until the whole of the bulb and about 2 inches of the stem are filled with mercury.

(*c*) The mercury still left in the funnel A is now poured out and the thermometer is heated until the mercury begins to boil. This is done to drive out any air bubbles entangled in the mercury.

(*d*) While the mercury is kept heated the neck B of the thermometer is sealed off in the Bunsen flame, and the thermometer is then allowed to cool for several days before being graduated.

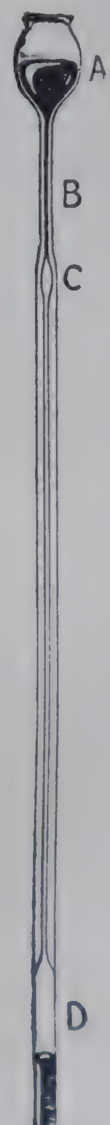

FIG. 1.—Thermometer in process of construction.

2. Determination of the fixed points of a thermometer.

The most convenient fixed points on the thermometer scale are

(i.) the *freezing point*, which corresponds to the temperature of melting ice,

(ii.) the *boiling point*, which is the temperature of water boiling under a standard atmospheric pressure.

Apparatus.—Thermometer constructed in Expt. 1, freezing point vessel, hypsometer, ice, pestle and mortar.

(i.) **Determination of the freezing point.**—(*a*) Place the thermometer in the clip C of the metal can A (Fig. 2). Break off some pieces of ice with a penknife and pound them in the mortar until the pieces are about $\frac{1}{3}$ in. across. Fill the can with the ice and place the receiver B underneath. Finally adjust the thermometer until the mercury thread is just level with the top of the can. After waiting a few minutes until the temperature is steady, note the position of the thread of mercury by means of a file mark. This position is the freezing point, which is marked 0° on Centigrade thermometers and 32° on a Fahrenheit thermometer.

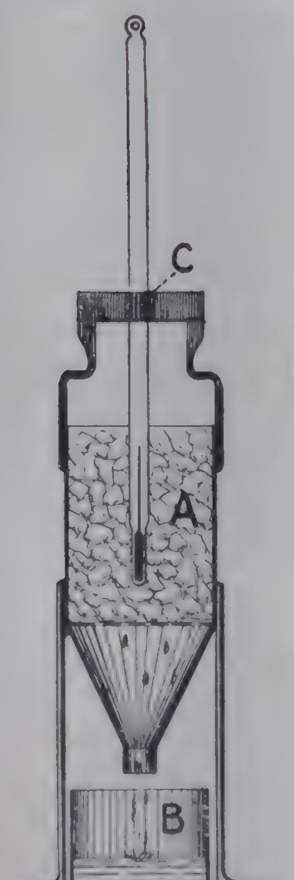

FIG. 2.—Apparatus for the determination of the freezing point on a thermometer.

(ii.) **Determination of the boiling point.**—For this purpose the *hypsometer* is used (Fig. 3). It consists of a double-jacketed metal cylinder A, on top of the tank B, containing boiling water. Push the thermometer through the hole in the cork at the top so that the steam surrounds the thermometer and escapes through the outlet C.

In accurate observations a manometer may be fitted at the

side so as to note whether the pressure inside is equal to that of the atmosphere.

Boil the water in the tank, and after waiting a few minutes arrange the thermometer so that the mercury column just appears above the cork. Mark the position of the mercury by means of a file and this will represent the boiling point. Read the laboratory barometer.*

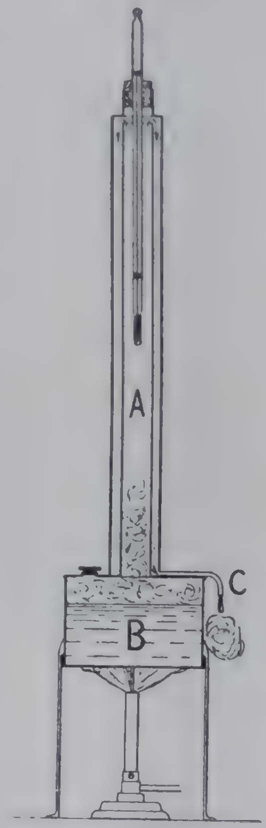

FIG. 3.—Hypsometer for the determination of the boiling point on a thermometer.

On a Centigrade thermometer the boiling point is marked 100° while on a Fahrenheit thermometer it is 212°, the distances between the two points being divided into 100° and 180° respectively on the two scales.

FIG. 4.—Thermometers showing Centigrade and Fahrenheit scales.

Fig. 4 represents a Fahrenheit and a Centigrade thermometer. A glance at the two thermometer scales shows that

$$\ldots{}^\circ\text{F.} = \frac{9}{5}\ldots{}^\circ\text{C.} + 32$$

and

$$\ldots{}^\circ\text{C.} = \frac{5}{9}(\ldots{}^\circ\text{F.} - 32).$$

3. Comparison of two thermometers.

It is often convenient and sometimes necessary to use two thermometers in an experiment, and as mercury thermometers seldom exactly agree it is very important to compare one with the other. In this experiment you are required to compare Centigrade and Fahrenheit thermometers.

* See note at the end of this chapter, p. 7.

Apparatus.—The two thermometers to be compared, a metal can filled with water, clamp and stirrer.

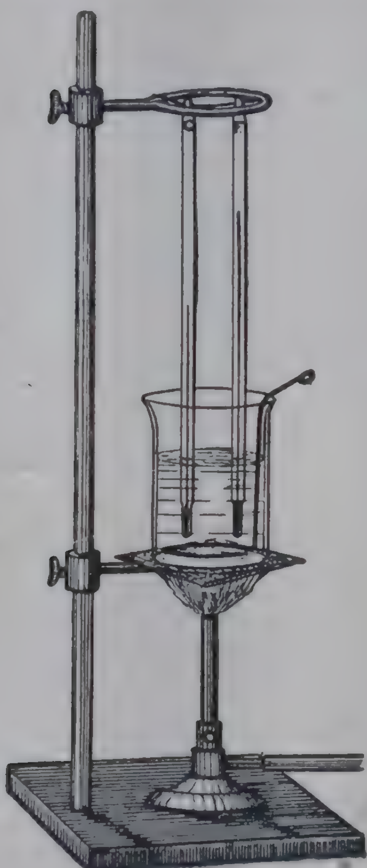

FIG. 5.—Apparatus for the comparison of two thermometers.

(*a*) Support the two thermometers in the tank of water so that they are equally immersed (Fig. 5).

(*b*) Heat the water gradually, keeping the whole of it well stirred. At about every 5° C. rise in temperature take readings on the thermometers simultaneously. Continue the readings until the boiling point is reached.

Note.—This boiling point is not necessarily 100° C. as the boiling point of water depends upon the pressure of the atmosphere and therefore varies with the altitude above sea level and with the height of the barometer.

(*c*) Pour a little cold water into the tank and stir well. When the temperature has fallen about 5° C. take readings simultaneously as before. Continue the observations for every 5° C. drop in temperature until the temperature of the room is reached.

(*d*) Tabulate your results as follows, placing the numbers down in the direction of the arrows :

No. of Expt	Centigrade Thermometer.			Fahrenheit Thermometer.			°F. reduced to °C.
	Up.	Down.	Average.	Up.	Down.	Average.	
1	18°.5	18°.7	18°.6	65°.0	65°.4	65°.2	18°.5
2	23°.2	23°.2	23°.2	73°.4	73°.6	73°.5	23°.1
...	↓	↑	......	↓	↑	......	......
...			......			......	......
...			......			...	......
16	94°.6	94°.8	94°.7	202°.8	203°.2	203°.0	95°.0
17	99°.7	99°.7	99°.7	211°.9	211°.9	211°.9	100°.0

(*e*) To obtain the numbers in the last column work out the results by the formula $\ldots°C. = \frac{5}{9}(\ldots°F. - 32)$.

(*f*) Plot a curve* having for ordinates the values of the Centigrade thermometer readings and for abscissae the corresponding readings on the Fahrenheit thermometer.

(*g*) Plot a second curve with the values of the Centigrade thermometer readings as abscissae and the readings in the last column as ordinates.

4. Special kinds of thermometers.

Students should be given special opportunities of handling and using the following instruments:

(i.) **Alcohol thermometer.**†—This thermometer being filled with alcohol is much more sensitive than a mercury thermometer on account of the greater expansion of the liquid. Further, the freezing point of alcohol being $-130°$ C., renders the thermometer suitable for the measurement of very low temperatures, whereas mercury freezes at $-39°.5$ C.

(ii.) **Clinical thermometer** (Fig. 6).—This instrument is used by medical men in taking the temperature of the human body, the normal temperature of which is about 98°.4 F.

Fig. 6.—Clinical thermometer.

(iii.) **High-temperature thermometer.** — The thermometric liquid is usually mercury, but the space above the liquid is filled with compressed nitrogen, which prevents the mercury from boiling at its normal boiling point, *i.e.* 357° C., and by using a special kind of glass, containing boron and silicon, temperatures up to 550° C. can be determined.

(iv.) **The maximum and minimum thermometer** is used for registering the highest and lowest temperature during any period.

* Directions for plotting curves are given in the Appendix.

† For experiments with liquid air a low temperature thermometer filled with liquid pentane will register temperatures down to $-200°$ C. with an accuracy of 2° C.

In *Six's self-registering thermometer* (Fig. 7) it will be noted that the bulb A is filled with alcohol, and separated from the top bulb D by means of the mercury thread BC. Two steel indexes are pushed

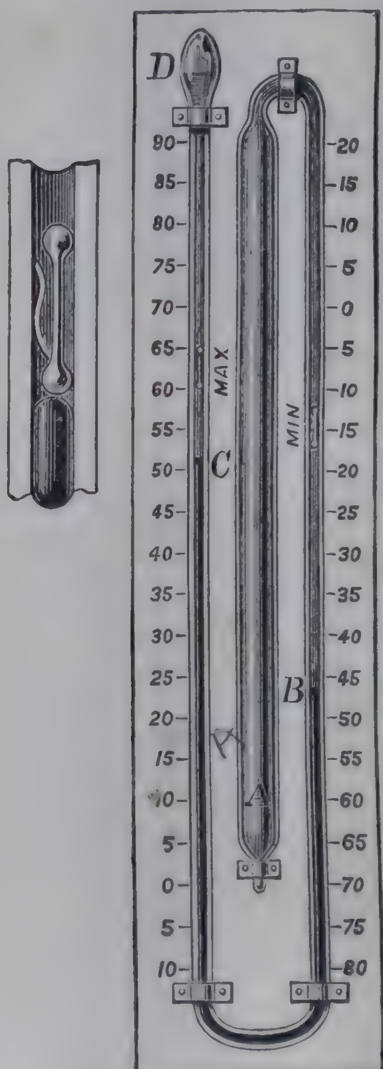

FIG. 7.—Six's maximum and minimum thermometer.

in front of the mercury column and record the lowest and highest temperature.

(v.) **Sensitive thermometer** (Fig. 8).—In this thermometer the bulb is comparatively large and consequently a slight increase in temperature produces a large displacement of the mercury thread. A reservoir at the top allows the thermometer

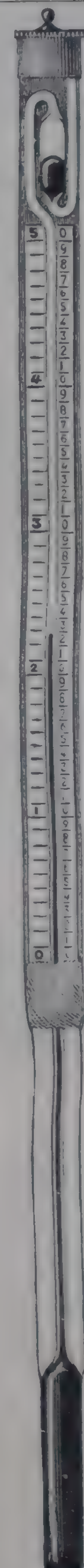

FIG. 8.—Sensitive mercury thermometer.

to be used for different ranges of temperature. If more mercury is required the bulb is warmed slightly until the thread reaches the reservoir when the thermometer is inverted until the mercury is connected and the requisite quantity is obtained. It is obvious that the instrument only measures *differences* of temperature.

(vi.) **Wet and dry bulb thermometer.**—(See Chapter X.)

(vii.) **Air thermometer.**—(See Chapter V.)

(viii.) **Electrical thermometers.** —(See Chapter XI.)

Note on Reading the Barometer Accurately.

Fortin's barometer (Fig. 9) is generally used for accurately reading the barometric height. A glass tube containing mercury is inverted and placed with the open end under mercury in the reservoir R, the height being observed on the scale S by means of a vernier. The screw A keeps the mercury in R at a constant level and just in contact with the ivory pointer P.

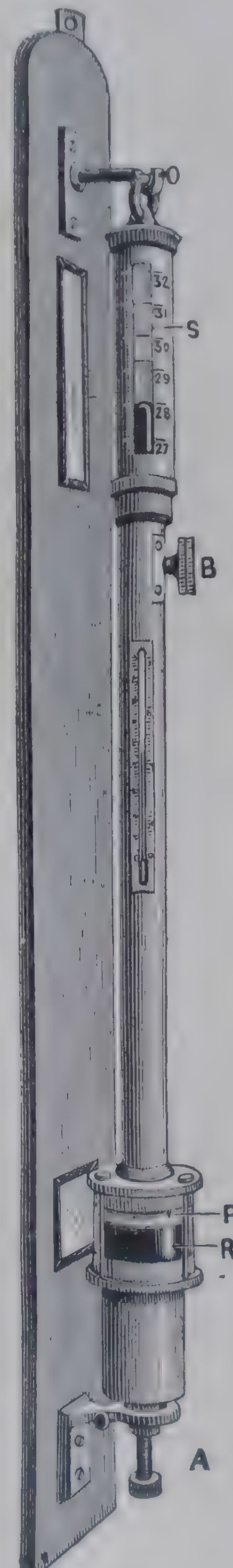

Fig. 9.—Fortin's barometer.

Read the height of the barometer h and then apply the following corrections :

(*a*) *Correction for the expansion of the mercury.* If h is the observed height at the temperature of the room $t°$ C. the height reduced to 0° C is

$$h_0 = \frac{h}{1 + \alpha t},$$

where α is the coefficient of expansion of mercury, *i.e.* 0.000181.

(*b*) *Correction for the expansion of the scale.* This expansion will cause the barometer to read too low so that the corrected height is equal to
$$\frac{h}{1+\alpha t}(1+\beta t),$$
where β is the linear coefficient of expansion of the scale. For glass $\beta=0.0000084$, for brass $\beta=0.000019$, for steel $\beta=0.000012$.

The above expression can be written $h[1-(\alpha-\beta)t]$.

(*c*) *Correction for latitude.* This is due to the fact that the value of gravity alters with the position on the earth's surface. For London this correction is +0.44 mm.; for Manchester +0.57 mm., and for Edinburgh +0.73 mm.

(*d*) The small error due to capillarity may be neglected.

(*e*) Corrections for errors in the scale divisions are usually included in the correction given with the Kew certificate of a barometer.

Additional Exercises.

1. Compare the two given thermometers for every 5° from 0° to 100° C.

2. Arrange the zero of the sensitive thermometer so that the range of the thermometer is 40°-45° C.

3. Compare the readings of a Bunsen's syphon barometer and a Fortin's barometer.

CHAPTER II.

ERRORS OF A MERCURY THERMOMETER.

5. Freezing point error.

Apparatus.—Centigrade and Fahrenheit thermometers. Freezing point apparatus used in Expt. 2 (i.).

(*a*) Place each thermometer in turn in the apparatus and surround it with melting ice as in Expt. 2 (i.). Note the freezing point in each case and enter your results thus:

CENTIGRADE THERMOMETER.

$$\begin{array}{rr} \text{True F.P.} = & 0^\circ.0 \\ \text{Observed F.P.} = & -0^\circ.2 \\ \hline \text{Error} = & +0^\circ.2 \end{array}$$

FAHRENHEIT THERMOMETER.

$$\begin{array}{rr} \text{True F.P.} = & 32^\circ.0 \\ \text{Observed F.P.} = & 32^\circ.3 \\ \hline \text{Error} = & -\ 0^\circ.3 \end{array}$$

The error is + or – according as the observed reading is below or above the true reading.

6. Boiling point error.

A correction must be made for the boiling point since water boils at 100° C. or 212° F. only when the mercury barometer reads 760 mm. in latitude 45°.

Apparatus.—Centigrade and Fahrenheit thermometers, hypsometer (Fig. 3).

(*a*) Thrust the thermometer through the hole in the cork so that the steam from the boiling water surrounds it. Adjust the thermometer so that the mercury column just appears above the cork. Note the reading on the thermometer and read the height of the barometer.* For ordinary pressures it is found that an alteration of 1° C. is produced by a difference of 27 mms. while in the Fahrenheit scale 15 mms. produce a difference of 1° F. In both scales the boiling point is raised by an increase of pressure and *vice versâ.*

Calculate the boiling point error thus :

Height of barometer = 752.4 mms.
Normal height = 760.0 mms.

Difference = 7.6 mms.

∴ Decrease in boiling point

$$=\frac{7.6}{27}=0^{\circ}.28\text{ C. or }=\frac{7.6}{15}=0^{\circ}.51\text{ F.}$$

Calculated B.P. at 752.4 mms. pressure
= 99°.72 C. or 211°.49 F.

Observed B.P. (Centigrade) = 99°.8 ∴ error = −0°.08.
Observed B.P. (Fahrenheit) = 212°.2 ∴ error = −0°.71.

7. Calibration of the bore of the thermometer tube.

If the bore of the tube were uniform a given volume of mercury would form a thread of the same length in any part of the tube. It is almost impossible to obtain a uniform bore so that it becomes necessary to calibrate the tube, *i.e.* to obtain the correction to be applied to a reading at any part of the stem due to inequality of the bore. The following exercise gives an idea as to how the cross section varies at different points.

Apparatus.—Piece of thermometer tubing at one end of which is attached a piece of indiarubber tubing, so that a

* See note on barometer readings, p. 7.

thread of mercury can be drawn into the tube. By noting the length of the thread at different parts of the tube the bore can be tested.

(*a*) Jerk the tube until the thread of mercury (about 2 cms. in length) has one end near the mark o° on the scale.

(*b*) Note the readings at the end of the thread ($t_1°$ and $t_2°$). Subtract these to obtain the length of the thread (l) measured in thermometer scale divisions.

(*c*) Calculate the scale reading at the centre of the thread. This will be $\left(t°_1+\frac{l}{2}\right)$.

(*d*) Jerk the thread down the tube through a distance equal to its own length and again take readings. Continue the observations until the other end of the tube is reached.

(*e*) Enter the results as follows :

1st end $t_1°$.	2nd end $t_2°$.	Length of thread $l=t_1°-t_2°$.	Centre of thread $t_1°+\frac{l}{2}$.	Cross section of tube $\frac{1}{l}$.
0.2	5.1	4.9	2.65	.204
5.0	9.8	4.8	7.40	.208
10.1	14.9	4.8	12.50	.208
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......

Since the volume of thread is constant the bore of the tube is proportional to $\frac{1}{l}$.

(*f*) Plot a curve having for abscissae the values of $\left(t_1°+\frac{l}{2}\right)$ and for ordinates the values of $\frac{1}{l}$.

8. Accurate calibration of the bore of a thermometer (Rudberg's method).*

Apparatus.—For this method we require a thermometer with an extended scale, so that the readings may be accurately estimated to o°.1. The thermometer is placed on a calibration

* Müller-Pouillet, *Lehrbuch der Physik*, vol. ii. p. 19.

stand (Fig. 10) and the readings taken with a vernier microscope. The lengths of the mercury threads used are $\frac{1}{2}$, $\frac{1}{3}$, and $\frac{5}{12}$ respectively of the distance between 0° and 100°, *i.e.* 50°, $33\frac{1}{3}$°, and $41\frac{2}{3}$°. The requisite length is obtained by warming the bulb of the thermometer until rather more than this length appears,

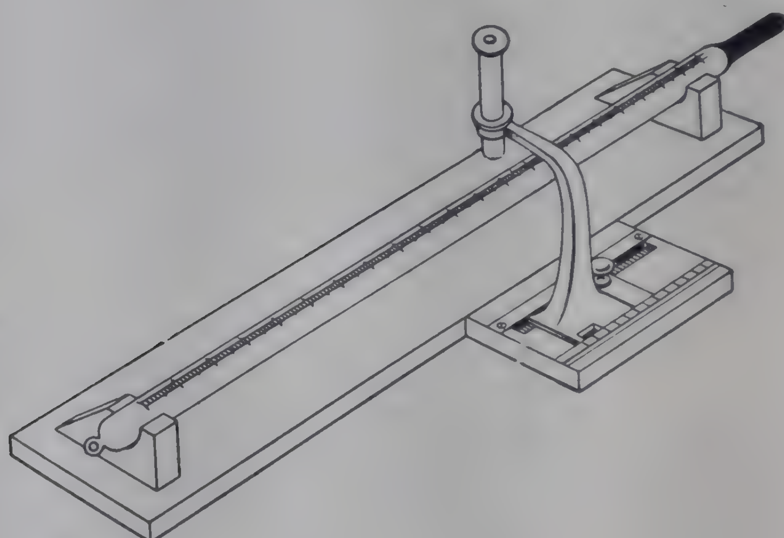

FIG. 10.—Support for the calibration of a thermometer.

when a sudden jerk of the thermometer will detach the column. After a few trials the length can be accurately judged.

In calibrating the thermometer by this method we can find the calibration corrections $K_1, K_2, K_3, \ldots K_{12}$, to be applied at the points $\frac{1}{12}, \frac{2}{12}, \frac{3}{12}, \ldots \frac{12}{12}$ of the length of the scale between 0° and 100°.

(*a*) Detach a thread of mercury equal in length to 50° and place it with one end opposite 0°. Read the other end near 50°. Subtract the readings to obtain A_0, the length of the thread. (Fig. 11.) Repeat this operation with the thread, starting at 50°, or the point marked 6, and we obtain the length of the thread A_6.

(*b*) Allow the thread to join the main column and then detach a thread of length equal to $33\frac{1}{3}$°, and in a similar manner place one end at the points, 0°, 16°.6, 33°.3, 50°, and 66°.6, and read the other ends, thus obtaining the lengths B_0, B_2, B_4, B_6, B_8.

(c) Detach a length of thread equal to $41\frac{2}{3}°$, and obtain its length at the points 0°, 8°.3, 16°.6, 25°, 33°.3, 41°.6, 50°, and 58°.3. From these observations calculate C_0, C_1, C_2, C_3, C_4, C_5, C_6, and C_7.

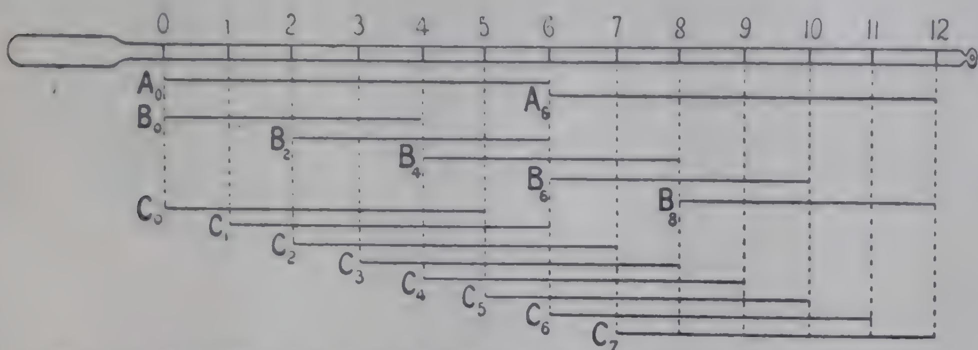

FIG. 11.—Lengths of mercury threads for the calibration of a thermometer by Rudberg's method.

Record your results thus :

THREAD A.	From	To	A_0.	A_6.
Up, . .	0.0	50.2	50.2	
	50.0	101.1		51.1
Down,. .	48.9	100.0		51.1
	−0.2	50.0	50.2	
Mean, . .	...	..	50.2	51.1

THREAD B.	From	To	B_0	B_2	B_4	B_6	B_8
Up, . .	0.0	33.2	33.2				
	17.0	49.9		32.9			
	33.0	66.2			33.2		
	50.0	83.7				33.7	
	66.0	99.5					33.5
Down, .	66.5	100.0					33.5
	49.4	83.0				33.6	
	32.9	66.0			33.1		
	17.1	50.0		32.9			
	−0.2	33	33.2				
Mean, .			33.2	32.9	33.15	33.65	33.5

Thread C.	From	To	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Up,	0.0	41.9	41.9							
	8.3	49.9		41.6						
	16.6	58.5			41.9					
	25.0	67.0				42.0				
	33.3	75.3					42.0			
	41.6	83.9						42.3		
	50.0	92.6							42.6	
	57.6	100.0								42.4
Down,	57.6	100.0								42.4
	49.0	91.5							42.5	
	41.0	83.3						42.3		
	33.1	75.0					41.9			
	24.7	66.7				42.0				
	16.4	58.3			41.9					
	8.4	50.0		41.6						
	−0.3	41.6	41.9							
Mean, .			41.9	41.6	41.9	42.0	41.95	42.3	42.55	42.4

If K_0, K_1, K_2, etc., are the corrections at the points 0, 1, 2, etc., then the length A of the thread **A** as reckoned on the scale of equal volumes is given by

$$2A = A_0 + A_6 + K_{12} - K_0$$

or $$A = \frac{A_0 + A_6 + K_{12} - K_0}{2} \quad \ldots\ldots (1)$$

also $$A = A_0 + K_6 - K_0 \qquad \therefore\ K_6 = A - A_0 + K_0 \quad \ldots\ldots (2)$$

Again $$3B = B_0 + B_4 + B_8 + K_{12} - K_0$$

$$\therefore\ B = \frac{B_0 + B_4 + B_8 + K_{12} - K_0}{3} \quad \ldots\ldots (3)$$

Also $$B_0 + K_4 - K_0 = B \qquad \therefore\ K_4 = B - B_0 + K_0 \quad \ldots\ldots (4)$$

and $$B_2 + K_6 - K_2 = B \qquad \therefore\ K_2 = B_2 - B + K_6 \quad \ldots\ldots (5)$$

and $$B_6 + K_{10} - K_6 = B \qquad \therefore\ K_{10} = B - B_6 + K_6 \quad \ldots\ldots (6)$$

and $$B_8 + K_{12} - K_8 = B \qquad \therefore\ K_8 = B_8 - B + K_{12} \quad \ldots\ldots (7)$$

Again $$C_0 + C_5 + K_{10} - K_0 = 2C \qquad \therefore\ C = \frac{C_0 + C_5 + K_{10} - K_0}{2} \quad \ldots\ldots (8)^*$$

and $$C_0 + K_5 - K_0 = C \qquad \therefore\ K_5 = C - C_0 + K_0 \quad \ldots\ldots (9)$$

and $$C_1 + K_6 - K_1 = C \qquad \therefore\ K_1 = C_1 - C + K_6 \quad \ldots\ldots (10)$$

and $$C_2 + K_7 - K_2 = C \qquad \therefore\ K_7 = C - C_2 + K_2 \quad \ldots\ldots (11)$$

and $$C_3 + K_8 - K_3 = C \qquad \therefore\ K_3 = C_3 - C + K_8 \quad \ldots\ldots (12)$$

and $$C_4 + K_9 - K_4 = C \qquad \therefore\ K_9 = C - C_4 + K_4 \quad \ldots\ldots (13)$$

and $$C_6 + K_{11} - K_6 = C \qquad \therefore\ K_{11} = C - C_6 + K_6 \quad \ldots\ldots (14)$$

* Since $C_2 + C_7 + K_{12} - K_2 = 2C \quad \therefore\ C = \frac{C_2 + C_7 + K_{12} - K_2}{2}$. The mean of the two values for C may then be substituted in the equations 9-14.

If we assume that the values of the corrections at K_0 and K_{12} (0° and 100°) are not required here we put $K_0 = 0$ and $K_{12} = 0$.

If we wish to include the corrections at the freezing point and boiling point we substitute for K_0 and K_{12} in the equations. If the freezing point is above 0° the value of K_0 is positive and *vice versâ*. Similarly for the boiling point.

Hence in our own example we have

$$A = \frac{A_0 + A_6}{2} = \frac{50.2 + 51.1}{2} = 50.65$$

$$\therefore\ K_6 = A - A_0 = 50.65 - 50.2 = +.45$$

$$B = \frac{B_0 + B_4 + B_8}{3} = \frac{33.2 + 33.15 + 33.5}{3} = 33.28$$

$$\begin{aligned}
K_4 &= B - B_0 &&= 33.28 - 33.2 = +.08\\
K_2 &= B_2 - B + K_6 &&= 32.9 - 33.28 + .45 = +.07\\
K_{10} &= B - B_6 + K_6 &&= 33.28 - 33.65 + .45 = +.08\\
K_8 &= B_8 - B &&= 33.5 - 33.28 = +.21
\end{aligned}$$

$$C = \frac{C_0 + C_5 + K_{10}}{2} = \frac{41.9 + 42.3 + .08}{2} = 42.14$$

$$\begin{aligned}
K_5 &= C - C_0 &&= 42.14 - 41.9 = +.24\\
K_1 &= C_1 - C + K_6 &&= 41.6 - 42.14 + .45 = -.09\\
K_7 &= C - C_2 + K_2 &&= 42.14 - 41.9 + .07 = +.12\\
K_3 &= C_3 - C + K_8 &&= 42.0 - 42.14 + .21 = +.07\\
K_9 &= C - C_4 + K_4 &&= 42.14 - 41.95 + .08 = +.27\\
K_{11} &= C - C_6 + K_6 &&= 42.14 - 42.55 + .45 = +.04
\end{aligned}$$

Arranging these results in tabular form, we have:

Reading.	Calibration Correction.
0°	$K_0 = 0$
8.33	$K_1 = -0.09$
16.67	$K_2 = +0.07$
25.00	$K_3 = +0.07$
33.33	$K_4 = +0.08$
41.67	$K_5 = +0.24$
50.00	$K_6 = +0.45$
58.33	$K_7 = +0.12$
66.67	$K_8 = +0.21$
75.00	$K_9 = +0.27$
80.33	$K_{10} = +0.08$
91.67	$K_{11} = +0.04$
100.00	$K_{12} = 0$

(*d*) Now draw a calibration curve with thermometer readings as abscissae and corrections as ordinates. Its form is shown

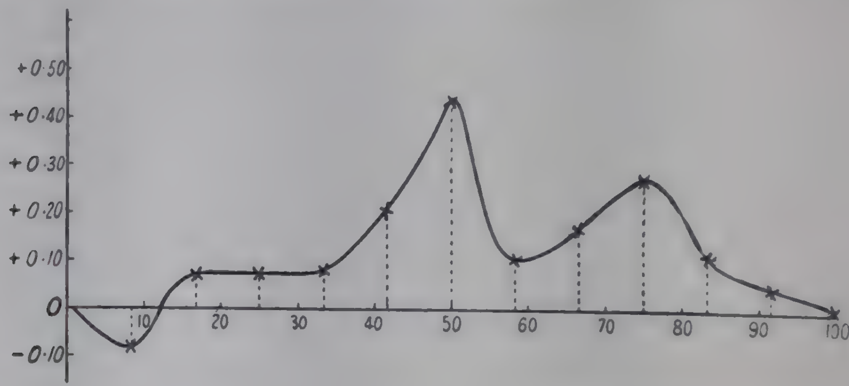

FIG. 12.—Calibration curve for a thermometer.

in Fig. 12. The correct reading of any temperature is obtained by adding the correction (from the curve) to the observed reading.

9. Correction for the temperature of the stem.

When a thermometer is used to determine a temperature it is often impossible to subject more than the bulb and a small portion of the stem to this temperature. The upper portion of the stem is thus at a different temperature from the rest of the tube and the reading will differ from that which would be indicated if the whole of it were immersed.

Apparatus.—Two Centigrade thermometers, hypsometer.

(*a*) Take one of the thermometers and place it in the hypsometer so that it is immersed up to the zero mark. Set the water boiling in the hypsometer and note the boiling point on the thermometer (read to $0^\circ.1$).

(*b*) Push the thermometer down to 20°, 30°, ... 100° and note the boiling point in each case.

The correction to be applied to a thermometer for the exposed stem is given by the formula :

$$T = t + .000143\, n(t - t'),$$

where T° = corrected temperature, t° = observed temperature, t'° = mean temperature of glass and mercury columns, n = number of divisions of mercury thread exposed.

(*c*) The temperature t'° may be observed by fastening a second small thermometer to the stem of the original thermometer under test.

(*d*) Calculate the correction for the observations in (*b*) and compare them with those in the Tables p. 194.

Additional Exercises.*

1. Find the boiling point reading for a given Centigrade thermometer

    (*a*) When immersed to 0° in boiling water.

    (*b*) When immersed as in (*a*) but with the stem surrounded with cotton-wool or asbestos.

    (*c*) When placed in the hypsometer as in Expt. 6.

2. Standardize a high temperature mercury thermometer (*a*) at 0° C., (*b*) at 100° C., (*c*) at the boiling point of sulphur. [Boil the sulphur in a piece of combustion tubing closed at the bottom end and surrounded with asbestos. Assume the temperature of the vapour from boiling sulphur is $444^{\circ}.5+.083(p-760)$ Centigrade, where p = barometric height in mms.]

3. Calibrate the given tube and make out a calibration curve therefor. (B.Sc. Lond. Hons. 1900.)

4. Determine the errors of the scale of the given thermometer and prepare a calibration curve for correcting its readings. (B.Sc. Lond. Hons. 1899.)

5. Calibrate the given thermometer and draw an error curve for it. (Ext. B.Sc. Lond. Hons. 1908.)

6. Calibrate the given thermometer tube between the two marks indicated. Express the results in a table of corrections. (Int. B.Sc. Lond. Hons. 1909.)

7. Determine the fixed points on the given thermometer stem and calibrate the stem so as to determine the correct readings at 25°, 50°, and 75° C. (Ext. B.Sc. Lond. Pass, 1911.)

8. Draw a calibration curve to allow for irregularities of the bore of the given thermometer. (Board of Education, 1906.)

9. Calibrate the scale of the given mercury thermometer to allow for irregularities in the bore of the tube, using a thread of approximately 20° in length. (Board of Education, 1911.)

* These exercises consist of (*a*) experiments suitable for test examinations and (*b*) exercises set in the practical examinations of the London University. Int. B.Sc. = Internal B.Sc. Examination.
Int. Sci. = Intermediate Science Examination.

CHAPTER III.

EXPANSION OF SOLIDS.

In general, all bodies expand under the influence of heat. A solid may expand in the direction of its length, breadth, and thickness, *i.e.* a solid has a linear, superficial and a cubical coefficient of expansion.

In the case of liquids and gases however, we have to deal with their volume or cubical expansion only. *The linear coefficient of expansion of a solid* is defined as *the increase in length of a bar of the solid* 1 *cm. in length when heated through* 1° *C.*

10. Comparison of linear expansions of different metals.

Apparatus.—A Ferguson's pyrometer (Fig. 13), which con-

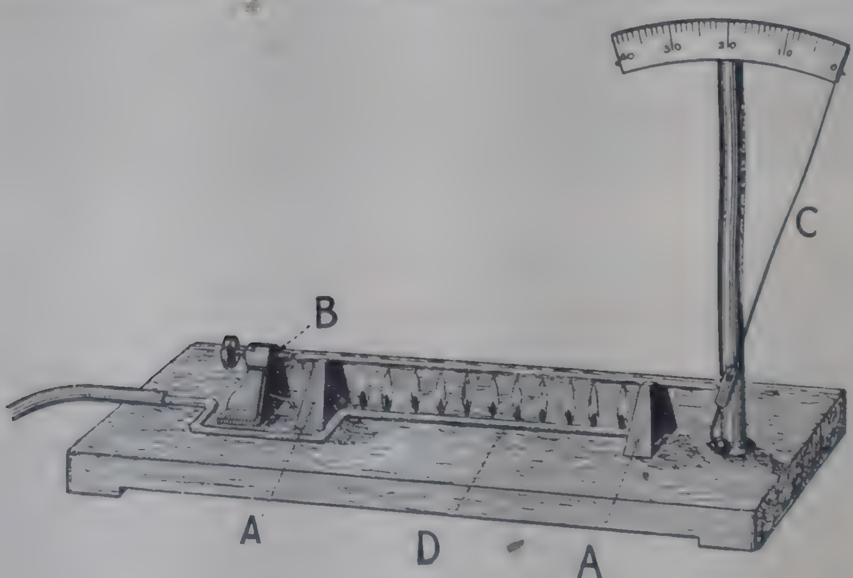

FIG. 13.—Ferguson's pyrometer.

sists of two slate supports A, A, on which the rod is laid so that one

end touches the screw B, while the other end is free to expand. The expanding bar pushes the pointer C over the scale and indicates the amount of expansion.

(*a*) Polish the given rods by means of sand paper and see that the rods are exactly the same length.

(*b*) Light the burner D and adjust the height of the flame until it will just touch the level of the rod when in position.

(*c*) Take hold of one of the rods with a pair of crucible tongs and quickly place in position on the apparatus, at the same time adjusting the screw B until the pointer C is at the zero mark. Note the exact time.

(*d*) Note the reading of the pointer at the end of two minutes and repeat the experiment with each rod in turn.

(*e*) Draw up a list of the metals in order of expansibility and compare this list with that given in the Tables p. 196.

11. Determination of the linear coefficient of expansion of a metal tube (Pullinger's method).

If a solid bar has a length l_1 at a temperature $t_1°$ and when heated to a higher temperature $t_2°$ its length is increased to l_2 then according to the definition

$$\alpha = \frac{l_2 - l_1}{l_1(t_2 - t_1)}$$

where α is the mean coefficient of expansion between the two temperatures t_1 and t_2.

By measuring l_1, l_2, t_1 and t_2 the coefficient α can be calculated.

Apparatus.—The metal tube (Fig. 14), closed at each end and having three lateral openings A, B and C. A and B are used for the passage of steam through the apparatus, while in C a thermometer is fixed by means of a short piece of indiarubber tubing. The tube is supported on a stand provided with a cross piece having a wooden clutch to secure the tube. On the top of the upright is placed the ~~glass~~ spherometer plate D supported on three levelling screws, and the tube just appears through a central hole in the glass plate. The lower end of the tube rests on a steel spike projecting from the wooden base.

(*a*) Accurately measure the length of the tube (l_1) with a metre scale.

(*b*) Insert the thermometer in C. Fix the metal tube in position and when the temperature has become constant note it ($t_1°$).

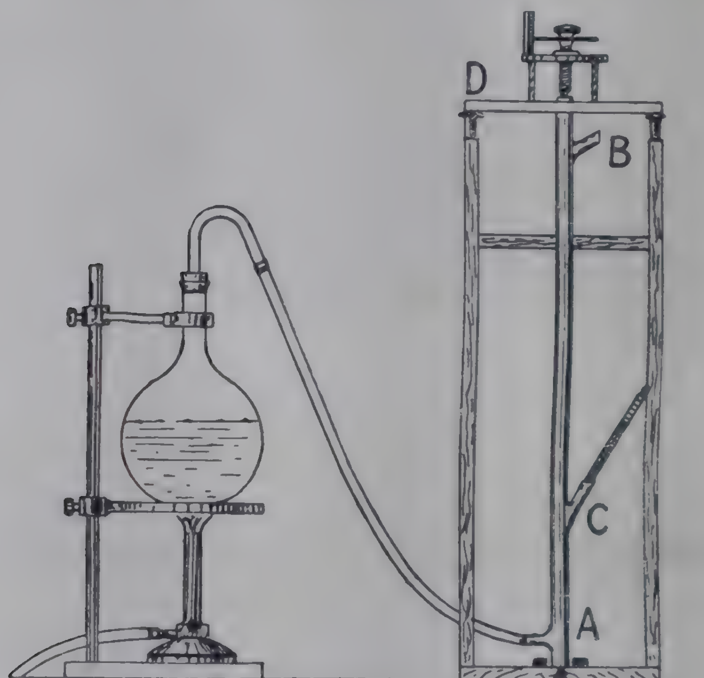

FIG. 14.—Pullinger's apparatus for the determination of the linear expansion of metals.

(*c*) Adjust the spherometer until the central screw just touches the upper end of the tube. Note the zero reading by means of a blacklead mark.

(*d*) Attach to the opening A, rubber tubing from a flask or can containing boiling water and pass steam through the tube for four minutes, and while it is still passing, adjust the spherometer and note the reading. Read the temperature $t_2°$.

(*e*) Calculate the expansion recorded on the spherometer and by adding this to the original length obtain the length after expansion (l_2).

(*f*) Calculate the value of the coefficient of expansion by means of the formula :

$$c = \frac{l_2 - l_1}{l_1(t_2 - t_1)}.$$

Enter the result as follows :

$$l_1 = 60.2 \text{ cms.}$$
$$t_1 = 15^\circ.1$$
$$t_2 = 100^\circ.2.$$

The pitch of the spherometer screw was 0.5 mm., and the graduated head had 500 divisions on it, *i.e.* 1000 divisions correspond to 1 mm.

The spherometer was turned through one complete turn + 362 divisions.

$$\therefore \quad \text{expansion} = \frac{500 + 362}{1000}$$
$$= 0.862 \text{ mm.}$$
$$= 0.0862 \text{ cm.}$$
$$l_2 = 60.2862 \text{ cms.}$$
$$\therefore \quad \alpha = \frac{0.0862}{60.2 \times 85.1} = 0.00001683.$$

12. Determination of the linear coefficient of expansion of a metal tube by the microscope method.

Apparatus.—A hollow metal tube A, A (Fig. 15), 6 mms. in diameter and about one metre in length with its ends resting on

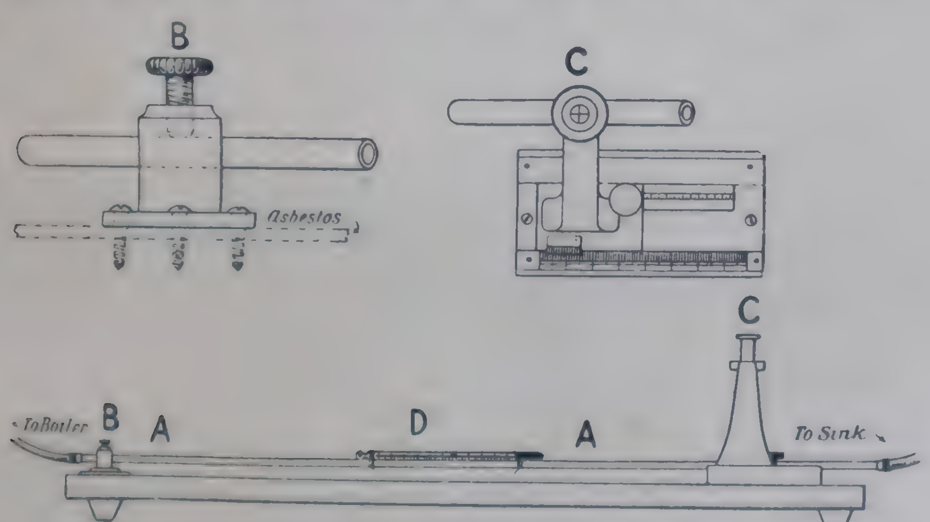

FIG. 15.—Microscope method for the determination of the linear expansion of a metal tube.

two large binding screws B, B. (An enlarged view of one of these screws is given in the figure.) One end of the tube is

clamped firmly in a screw while the other end is passed loosely through another screw and is free to expand. The screws rest on asbestos pads and are fixed to a wooden base. Near the free end of the metal tube is fixed a reading microscope C, which has a vernier reading to 0.05 mm. The thermometer D is fixed to the tube in order to measure its temperature.

(*a*) With a metre scale measure the length of the tube (l_1) between the centre of the screw at the fixed end and a scratch made near the free end.

(*b*) Note the temperature (t_1°) of the rod on the attached thermometer.

(*c*) Focus the reading microscope so that the cross wires are over the scratch on the tube. Note the vernier reading.

E.g. If the zero reading on the scale is between 8.6 and 8.7 cms. and the division 14 on the vernier coincides with a scale division, the reading is $8.6+(14\times 0.005)=8.67$ cms. since the 'least count' of the vernier is 0.05 mm. $=0.005$ cm.

(*a*) Pass steam through the tube for about ten minutes and again focus the microscope and read the vernier. Note the temperature (t_2°) on the thermometer.

(*e*) Calculate the coefficient of expansion from the formula:

$$C=\frac{l_2-l_1}{l_1(t_2-t_1)}$$

e.g.

$$l_1=126.6 \text{ cms.}$$
$$t_1=17^\circ.1$$
$$t_2=98^\circ.7$$

Vernier microscope reading (1) $=8.670$ cms.
(2) $=8.795$ cms.

Expansion of rod $(l_2-l_1)=0.125$ cms.

$$\therefore\ C=\frac{0.125}{126.6\times 81.6}=0.0000121.$$

13. Determination of the linear coefficient of expansion of a solid rod. (Weedon's method.)

Apparatus.—The rod is supported in a zinc trough (Fig. 16) about 100 cms. in length which contains water, oil or other liquids for heating. At each end of the trough is a

stuffing box through which passes a short piece of glass tubing, one end being in contact with the rod while the other end is adjacent to the screw of a micrometer gauge.* The gauges are screened off from the trough while the supports for the burner are immersed in cold water.

FIG. 16.—Weedon's apparatus for the determination of the linear expansion of a metal rod.

(*a*) Fill the tank with cold water of temperature (t_1°).

(*b*) Measure the length of the rod (l) in the trough by means of a pair of beam compasses.

(*c*) Screw up the micrometer gauges at each end until they touch the extremities of the glass rods which in turn are in contact with the rod under test. Note the gauge readings.

(*d*) Screw back the micrometer gauges until they are well out of the way of the greatest expansion of the bar. Heat the liquid in the trough, and when the maximum temperature (t_2°) is reached screw up the gauges until they are again in contact and again note the readings.

(*e*) From the previous readings calculate the expansion of the rod at each end and by addition obtain the total expansion (ϵ).

(*f*) Calculate the linear coefficient of expansion (α) from the formula

$$\alpha = \frac{\epsilon}{l(t_2 - t_1)}.$$

14. Superficial and cubical expansions of solids.

Suppose a surface of 1 sq. cm. of a substance whose coefficient of linear expansion is α, is heated from 0° to t°. The area of the surface is evidently increased to

$$(1 + \alpha t)^2 = 1 + 2\alpha t + \alpha^2 t^2.$$

* The apparatus might be improved by using one micrometer gauge and arranging for the metal rod to form part of an electric circuit containing a battery and electric bell.

But since the last term of this expression is very small and may be neglected, the area at $t° = 1 + 2\alpha t$ *i.e.* the superficial coefficient of expansion of a solid is 2α or twice the linear coefficient.

If a cube of 1 cm. length, breadth and thickness be heated from 0° to $t°$ its volume at $t°$ will become

$$(1+\alpha t)^3 = 1 + 3\alpha t + 3\alpha^2 t^2 + \alpha^3 t^3,$$

or, since the last two terms are negligible the volume $= 1 + 3\alpha t$ *i.e.* the cubical coefficient of expansion of a solid is 3α or three times the linear coefficient.

For glass $\alpha = 0.0000084$ (approx.).

∴ the cubical coefficient of glass is 0.0000252.

Additional Exercises.

(1) Determine the expansion of a solid metal rod by using two reading microscopes and by observation of the expansion on heating the rod inside a horizontal glass tube.

(2) Plot a curve showing the expansion of a metal rod for every 10° between 0° and 100° C.

(3) Find the coefficient of expansion of a zinc rod by observing its increase in length when jacketed with steam.

(Inter. Sci. Hons. Lond. 1896.)

(4) Find the coefficient of linear expansion of the given tube.

(Ext. B.Sc. Lond. Pass, 1909.)

CHAPTER IV.

EXPANSION OF LIQUIDS.

In dealing with liquids we have only to consider the cubical expansion, but it will be seen that the containing vessel will affect the result.

15. The expansion of the containing vessel.

Apparatus.—Flask fitted with rubber stopper through which passes a long glass tube (Fig. 17.)

(*a*) Fill the flask with cold water coloured with cochineal and push the cork into the neck of the flask so as to cause the water to rise up the tube.

(*b*) Plunge the flask into hot water, and notice that the liquid first *falls* in the tube owing to the vessel expanding before the heat has time to reach the liquid. After a few seconds the liquid *rises* in the tube, showing that although the glass vessel is expanding the liquid expands at a much greater rate.

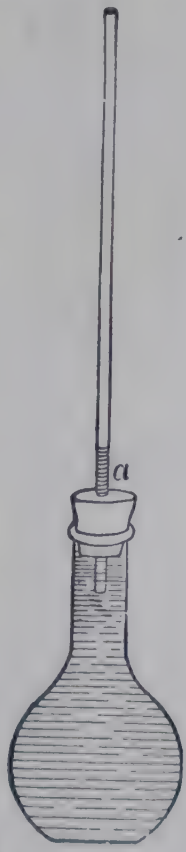

FIG. 17.—Flask fitted with tube to show *real* and *apparent* expansion of a liquid.

From this experiment it is shown, therefore, that the *apparent* expansion of the liquid is less than its *absolute* or *real* expansion owing to the expansion of the vessel. It may be proved that the coefficient of absolute expansion of a liquid is equal to the coefficient of apparent expansion, together with the coefficient of cubical expansion of the containing vessel. Knowing any two of these three quantities we can thus find the remaining one.

16. Determination of the cubical expansion of a liquid by the bulb tube.

Apparatus.—Glass bulb tube, metal heater, various liquids, thermometer, stirrer.

The glass bulb A (Fig. 18) has a tightly fitting graduated stem B divided into c.cs., and on the bulb is marked its capacity in c.cs. up to the zero mark on the stem. By this means the volume of the liquid in the bulb and stem is easily found.

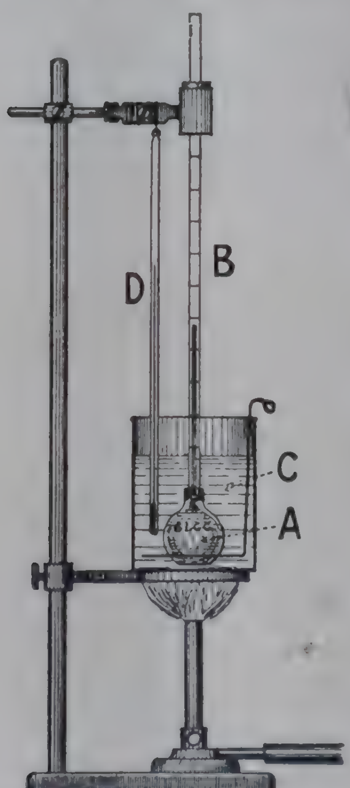

FIG. 18.—Apparatus to determine the expansion of a liquid by the graduated bulb tube.

The glass bulb has a capacity of about 65 c.c., and the stem is graduated from 0 to 10 c.cs.*

The stem is rather wide and short in order to be immersed more in the boiling water. The volume of liquid in the stem can easily be read off to 0.01 c.c.

(*a*) Fill the bulb and stem up to the zero mark with the liquid, and support it in the heater C by means of a clamp. Suspend a thermometer D from the same clamp.

(*b*) Fill the heater with cold water, stir well, and read off the temperature of the tank (t_1°) and the volume of the liquid (V_1).

(*c*) Place a large Bunsen burner under the tank and heat the water, keeping it well stirred, until the boiling point is reached. The liquid will not, however, have finished expanding until three or four minutes afterwards. When the height of the liquid in the stem is quite constant take readings of the temperature (t_2°) and volume (V_2).

* J. Young and C. R. Darling have designed an apparatus in which the graduated stem is fused in the side of the bulb and the thermometer is fixed in the ground stopper. For convenience in filling the bulb a capillary tube and tap are fitted to the lower end, and the bath is heated by means of a steam coil.

The apparent coefficient of expansion of the liquid (c)

$$=\frac{V_2 - V_1}{V_1(t_2 - t_1)}.$$

To this result add 0.000025 in order to obtain the absolute coefficient of expansion of the liquid.

e.g. Turpentine

$V_1=66.14$ c.cs. $t_1=14°.1$

$V_2=71.91$ c.cs. $t_2=99°.8$,

∴ apparent coefficient of expansion (calculated)

=0.001019,

real coefficient of expansion

=0.001044.

17. Determination of the apparent coefficient of expansion of a liquid by the specific gravity bottle.

Apparatus.—Specific gravity bottle, heater, thermometer, liquid, stirrer.

(*a*) Clean the specific gravity bottle by washing it successively with ammonium hydrate, dilute acid, water and ether; dry with the blowpipe and determine its weight (W).

(*b*) Immerse the bottle up to the neck in a tank of water at the temperature of the room and fill it with the given liquid. Replace the stopper, and if no air bubbles are present dry the outside and weigh the bottle and contents (W_1). Note the temperature of the water tank ($t°$).

(*c*) Suspend the bottle by a thread so that it is immersed up to the neck in the water in the heater and raise the temperature until the water begins to boil. After boiling ten minutes take the bottle out, dry on the outside, and weigh the bottle and contents (W_2). Note the temperature of the boiling water (T°).*

The weight of the liquid in the bottle is now $W_2 - W$, and the expansion is given by $W_1 - W_2$. A weight of liquid $(W_2 - W)$ will therefore expand by a quantity $(W_1 - W_2)$ when the temperature is raised from $t°$ to T°.

* In all cases where temperatures higher than 100° C. are required it will be necessary to fill the heater with liquids of higher boiling point, *e.g.* aniline 182° C., ethyl benzoate 211° C., melted paraffin, or a fusible metal bath made by mixing one part of lead to two parts of bismuth. The latter is fluid above 120° C.

The coefficient of apparent expansion (C) is therefore

$$= \frac{W_1 - W_2}{(W_2 - W)(T - t)}.$$

e.g. Glycerine.

$$T = 100^\circ.1$$
$$t = 12^\circ.9$$
$$W = 22.21 \text{ grs.}$$
$$W_1 = 85.25 \text{ ,,}$$
$$W_2 = 82.46 \text{ ,,}$$
$$\therefore C = \frac{2.79}{60.25 \times 87.2} = 0.000514$$

18. Other forms of expansion apparatus.

Instead of using a specific gravity bottle to determine the coefficient of expansion of a liquid, various other forms of apparatus may be used, viz.:

(*a*) The **Dilatometer** (Fig. 19), is blown from a piece of glass tubing and has a narrow constriction in the neck. A mark

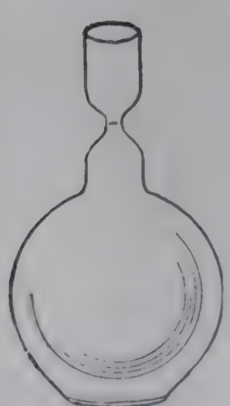

FIG. 19.—Dilatometer.

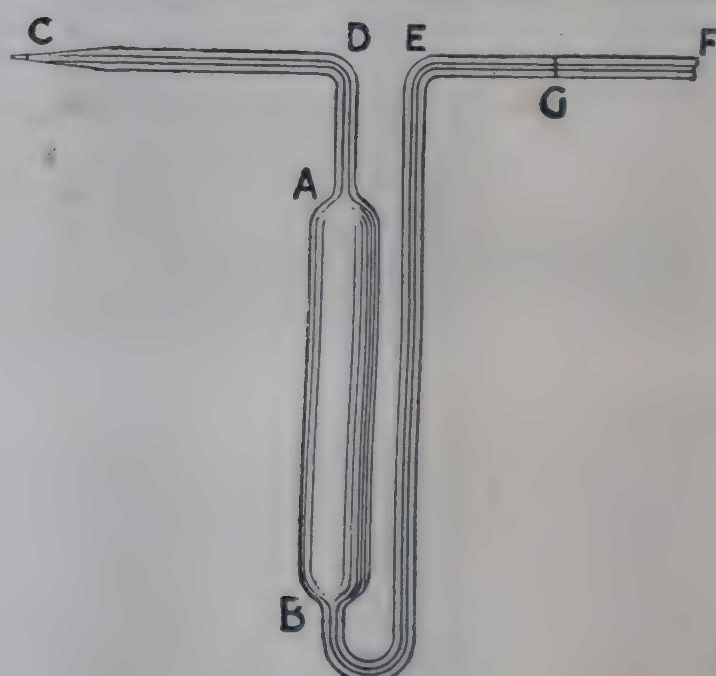

FIG. 20.—Pyknometer.

at this constriction serves to indicate the position of the liquid in the bottle, and the amount of expansion of the liquid is

determined by taking out the excess with a small pipette and running it into a weighed crucible.

(*b*) The **Pyknometer** (Fig. 20), consists of a wide tube AB connected to two horizontal fine tubes CD and EF. An india-rubber tube is attached at F and the liquid drawn in as far as the mark G. On heating the pyknometer, the liquid will flow out in both directions, and it is again adjusted to the mark G.*

FIG. 21.—Weight thermometer for the determination of the expansion of liquids.

(*c*) The **weight thermometer** (Fig. 21), has a large cylindrical bulb while the stem, like that of a mercury thermometer, is of thick capillary tubing with a fine bore. The method of filling the instrument is similar to that employed in filling a mercury thermometer, the expansion of the contained liquid being determined by weighing the portion expelled on heating the thermometer.

19. Determination of the absolute expansion of a liquid by Dulong and Petit's Method.

This method depends on the hydrostatic principle that if a liquid be poured into a U-tube it stands at the same height in each arm of the tube, but if two liquids which do not mix be poured one into each arm, then the height of each liquid above the common level is inversely proportional to its density.

If the same liquid is used but one arm is surrounded with cold water and the other with steam, the same principle holds good.

Let H = height of the hot column of liquid.

h = ,, cold ,, ,,

d_T = density of hot column.

d_t = ,, cold column.

Then $$\frac{H}{h} = \frac{d_t}{d_T}. \qquad (1)$$

* The Pyknometer and weight thermometer may be cleaned by washing with a potassium bichromate and sulphuric acid mixture, and afterwards with distilled water. The tube is then dried by drawing through it ether vapour and finally a current of cold dry air.

But since the mass of each column is the same and is equal to volume × density,

$$\therefore \quad V_t d_t = V_T d_T$$

where V_t, V_T are the volumes in the two cases.

$$\therefore \quad \frac{d_t}{d_T} = \frac{V_T}{V_t} = \frac{V_0(1+\alpha T)}{V_0(1+\alpha t)} = \frac{1+\alpha T}{1+\alpha t} \quad \text{......................(2)}$$

where α = the absolute coefficient of expansion of the liquid.

Substituting in equation (1) we have

$$\frac{H}{h} = \frac{1+\alpha T}{1+\alpha t},$$

hence

$$\alpha = \frac{H-h}{hT-Ht}.$$

Apparatus.—A glass U-tube AA (Fig. 22) about 6 mms. diameter, and 80 cms. in height filled with the liquid under test. As the difference in level of the two columns is small, a liquid should be chosen which has a high coefficient of expansion. Aniline answers the purpose well as it will show about 6 cms. difference in level for the above dimensions.

One arm of the U-tube is surrounded by a wide tube C through which cold water is passed. The other arm is surrounded by a similar tube D connected to a water tank E so that either steam or boiling water may be passed through. The whole apparatus is fixed to a wooden stand by means of the metal bands *b*, *b*. Inside each tube are placed thermometers to register the temperatures of the liquid columns.

A T-piece fitted with a tap may be fixed to the lower tube so as to adjust the height of the liquid columns, and also to empty the apparatus.

(*a*) Pour the aniline into the U-tube so that it stands about 5 cms. from the top of the tubes C and D.

(*b*) Connect the tube C to the water supply and keep a continuous stream of water running through.

(*c*) Connect the tube D to the water tank E. If steam is to be passed through, connect the outlet of the tank to the upper end of D, and connect the lower end of D to the sink. If hot water is to be run through, connect up, as in Fig. 22. Higher temperatures can be obtained by filling the tank with turpentine or aniline.

(*d*) When the hot column of liquid in D has finished expanding read its height (H) in cms., and note its temperature (T°).

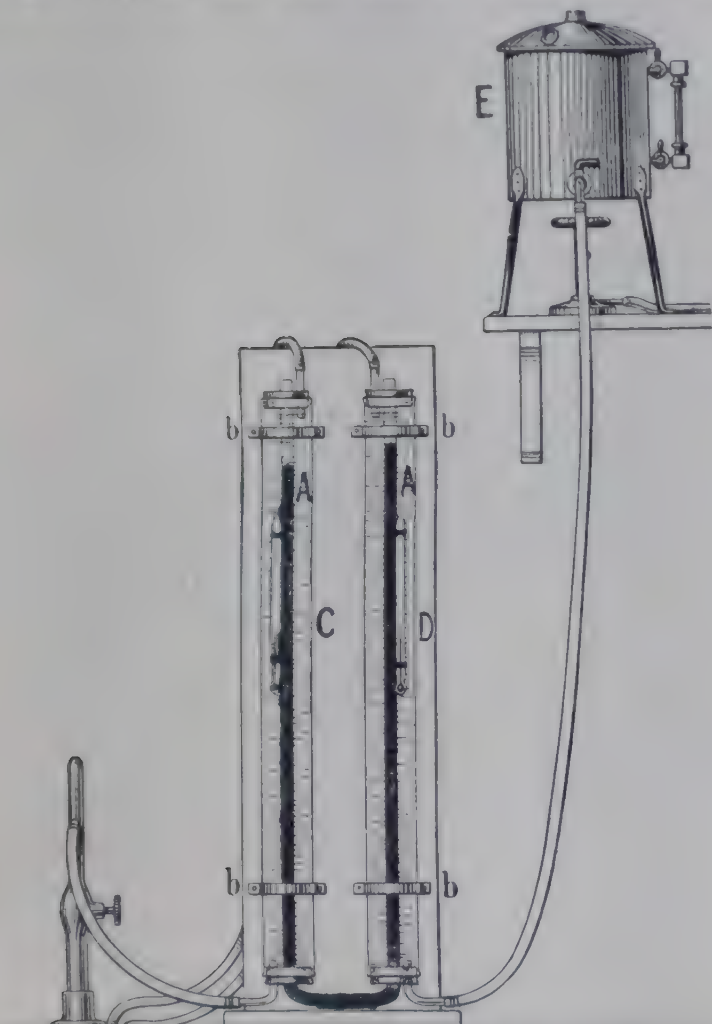

FIG. 22.—Apparatus for the determination of the absolute expansion of liquids by Dulong and Petit's method.

(*e*) Read the height (h) and temperature ($t°$) of the cold column

(*f*) Calculate the value of α by the formula :

$$\alpha = \frac{H - h}{hT - Ht};$$

e.g. Aniline

$$H = 61.7 \text{ cms.}$$
$$h = 57.0 \text{ cms.}$$
$$T = 99°.9$$
$$t = 8°.8$$

$$\therefore \alpha = \frac{4.7}{5694.3 - 543.0} = 0.000913.$$

(*g*) If $(H - h)$ is small compared with H, show that

$$\alpha = \frac{H - h}{h(T - t)}.$$

Calculate the value of α by means of this formula, and compare the two results.

20. Determination of the coefficient of cubical expansion of a liquid by Regnault's method.

Apparatus.—The parts of Regnault's apparatus are :

(1) The vertical tubes AA and BB (Fig. 23), each about 60 cms. in length and about 6 mms. in diameter. The tube AA is surrounded by a wide tube through which steam may be passed, while the tube B is surrounded by a similar tube through which a supply of cold water is maintained. Thermometers are attached to each tube.

(2) The horizontal tube EE provided with a small opening *e* at the upper side.

(3) The upright tubes C and D which meet at F, where there is a stop-cock in order that air can be forced into the apparatus by a small hand-pump. C and D are about 25 cms. in height, and are graduated in mm. divisions.

(*a*) Pour the given liquid down the tubes A and B, and by opening the tap F and blowing in air, arrange the liquid so that it just rises slightly above the level of the horizontal tube EE, and in C and D to one half their heights. The tube EE and also the tubes C and D are kept at the same temperature as the water in B by means of cotton wick connected to the inside of B.

(*b*) Close the stop cock at F. Start the supply of steam and water through the apparatus until the temperatures registered on the thermometers are quite steady. The hot column will expand, and any excess of liquid flows out of the opening at *e*.

(*c*) Measure H_1 and H_2, the heights of the liquids in the large tubes.

(*d*) Note the heights (h_1 and h_2) of the liquid in the tubes C and D.

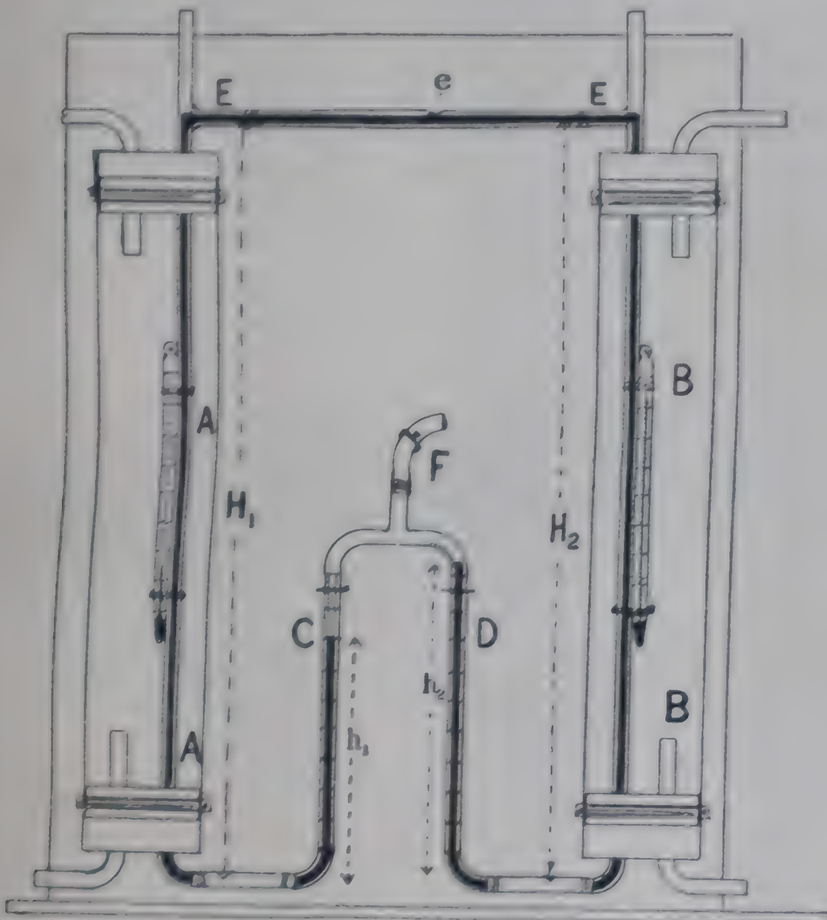

FIG. 23.—Apparatus for the determination of the absolute expansion of a liquid by Regnault's method.

(*e*) Note the temperatures T° and $t°$ on the thermometers in A and BB respectively.

Then if α = coefficient of expansion of liquid
d_T = density of liquid at T°
d_t = ,, ,, $t°$
d_0 = ,, ,, 0°

$$H_1 d_T - h_1 d_t = H_2 d_t - h_2 d_t.$$

$$\therefore \quad H_1 d_T = (H_2 + h_1 - h_2) d_t.$$

But
$$\begin{cases} d_T = \dfrac{d_0}{1 + \alpha T}, \\ d_t = \dfrac{d_0}{1 + \alpha t}. \end{cases}$$

$$\therefore \quad \frac{H_1}{1+\alpha T} = \frac{H_2 + h_1 - h_2}{1+\alpha t}$$

$$\therefore \quad \frac{1+\alpha T}{1+\alpha t} = \frac{H_1}{H_2 + h_1 - h_2}.$$

If $h_2 - h_1 = x$ (say)

then $$\frac{1+\alpha T}{1+\alpha t} = \frac{H_1}{H_2 - x}.$$

α is obtained from this equation by substituting the values found for H_1, H_2, h_1, h_2, T, and t.

e.g.

$$\begin{aligned} H_1 &= 81.8 \text{ cms.}, \\ H_2 &= 81.7 \text{ cms.}, \\ h_1 &= 8.2 \text{ cms.}, \\ h_2 &= 14.9 \text{ cms.}, \\ t &= 16^\circ.2, \\ T &= 99^\circ.6, \\ x &= 6.7 \text{ cms.}; \end{aligned}$$

$$\therefore \ \alpha \text{ (calculated)} = 0.00106.$$

21. Determination of the cubical coefficient of expansion of a liquid by Matthiessen's method.

This method depends upon the principle of Archimedes, viz. when a body is weighed in a liquid the loss in weight is equal to the weight of an equal volume of the liquid displaced.

If the liquid is heated the immersed solid will expand and displace a larger volume, but at the same time the liquid expands and becomes less dense, so that the loss in weight will depend on the difference between the two coefficients of expansion.

Apparatus.—An air thermometer bulb about 3″ diameter is filled with enough mercury to sink it in glycerine. The bulb is sealed up and suspended by a silk thread from one pan of a balance (Fig. 24). The balance is supported on a wooden stand and a hole is drilled under the pan to allow the bulb to be immersed in a vessel containing the liquid under test.

(*a*) Suspend the bulb so that it hangs freely, and find its weight in air (W).

(*b*) Place the vessel containing the liquid under the pan so that the bulb is completely immersed. Find the apparent

weight of the bulb (W_1) and note the temperature of the liquid ($t_1°$).

(*c*) Raise the temperature of the liquid to another temperature ($t_2°$). Stir well, and again find the apparent weight of the bulb (W_2).

(*d*) Find the weight of liquid displaced by the bulb at

$$t_1° = W - W_1.$$

Call this weight w_1.

(*e*) Similarly the weight of liquid displaced at $t_2°$

$$= W - W_2 = w_2 \text{ (say)}.$$

(*f*) Then the coefficient of expansion of the liquid (β) is given by the formula

$$\beta = \frac{w_1 - w_2}{w_2(t_2 - t_1)} + \alpha,$$

where α = cubical coefficient of expansion of glass.

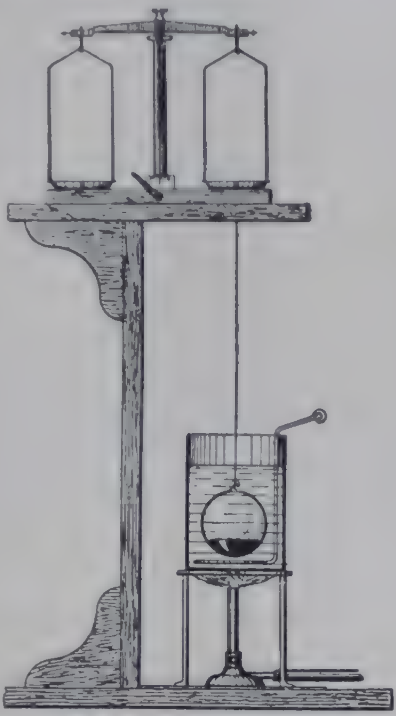

FIG. 24.—Apparatus to determine the expansion of a liquid by Matthiessen's method.

The above formula may be proved as follows:

Let V_1 = volume of the bulb at $t_1°$,
V_2 = volume of the bulb at $t_2°$,
d_1 = density of liquid at $t_1°$,
d_2 = density of liquid at $t_2°$.

Then since mass = volume × density,

$$w_1 = V_1 d_1 \quad \text{(1)}$$

$$w_2 = V_2 d_2 \quad \text{(2)}$$

Also for any temperature t,

$$V_t = V_0(1 + \alpha t),$$

$$d_t = \frac{d_0}{1 + \beta t}.$$

Where α = coefficient of expansion of the solid,
β = coefficient of expansion of the liquid.

$$\therefore \quad \frac{w_1}{w_2} = \frac{V_1 d_1}{V_2 d_2}$$

$$= \frac{1 + \alpha t_1}{1 + \alpha t_2} \cdot \frac{1 + \beta t_2}{1 + \beta t_1};$$

or, since α and β are small quantities,

$$\frac{w_1}{w_2} = \frac{1+\beta(t_2-t_1)}{1+\alpha(t_2-t_1)}$$
$$= 1 + (\beta-\alpha)(t_2-t_1);$$

$$\therefore \qquad \beta = \frac{w_1 - w_2}{w_2(t_2-t_1)} + \alpha, \text{ as above.}$$

e.g. $W = 343.0$ grams,
$W_1 = 26.4$ grams, $\therefore\ w_1 = 316.6$ grams,
$W_2 = 44.6$ grams, $\therefore\ w_2 = 298.4$ grams,
$t_1 = 17°.6$,
$t_2 = 136°.2$;

$\therefore$ β (calculated) $= 0.000511 + 0.000025$
$= 0.000536$.

22. Determination of the maximum density point of water.

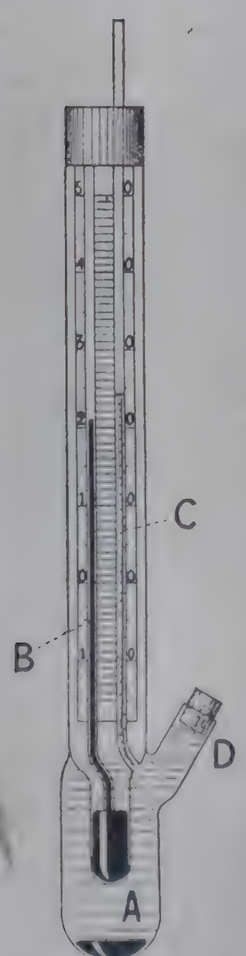

FIG. 25.—Apparatus to determine the maximum density point of water.

Apparatus.—A glass vessel A (Fig. 25) into which is fused the thermometer B, while the tube C serves as an indicator for the volume of the water and a side tube D fitted with a cork to fill the apparatus. The thermometer scale serves to measure the height of the liquid in the tube C.

(*a*) Fill the tube A with distilled water free from air bubbles, and insert the cork in D so as to force the water half way up the tube C. Place the apparatus in a metal vessel containing water at the temperature of the room.

(*b*) Note the temperature on the thermometer B, and also note the height of the water in C.

(*c*) Make a freezing mixture with equal weights of ice and salt. Add sufficient of this mixture to the water in the metal vessel so as to cause the temperature to drop about 2°. Stir well for two minutes, and then note the readings on B and C.

(*d*) Repeat the observations at intervals of 2° until the water in the apparatus freezes.

(*e*) Plot a curve with temperatures as abscissae and corresponding heights of water in C as ordinates, and from this curve deduce the temperature at which the volume of water is least, *i.e.* the maximum density point. The curve should be similar to that given in Fig. 26.

(*f*) The true expansion of the water may be observed by eliminating the expansion of the glass bulb as follows: Place in the bulb A a quantity of mercury, the volume of which is $\frac{1}{7}$th of the volume of the bulb. The expansion of the mercury will tend to decrease the volume of the bulb, while the expansion of the bulb will tend to make the volume larger in the same proportion, since the expansion coefficients of mercury and glass are 0.00018 : 0.000026, or approximately 7 : 1.

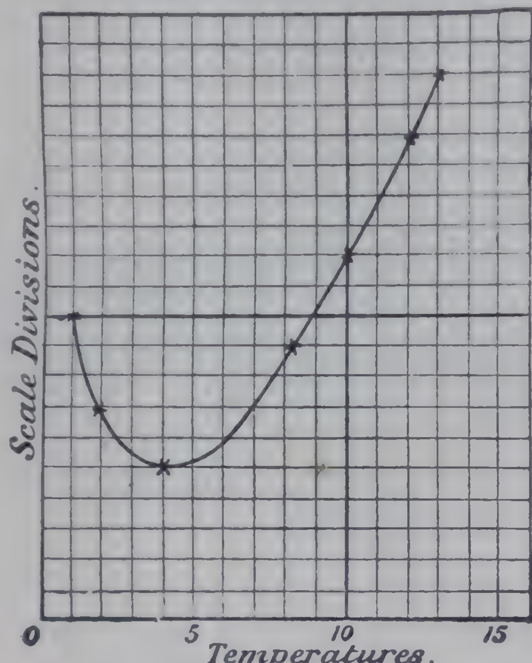

FIG. 26.—Curve showing the maximum density point of water.

Note.—C. R. Darling has suggested a simple method for the determination of the temperature of equal density of two liquids, *e.g.* water and aniline. A U-tube about 40 cms. long having a narrow bore connection is placed in a water bath heated by a steam coil. Water is placed in one limb of the U-tube and aniline in the other, and when cold the aniline column is lower than the water. On heating, the aniline expands more than the water, and the temperature of equal density is found when the columns of the liquid are equal in height.

ADDITIONAL EXERCISES.

(1) Measure the absolute expansion of (*a*) lubricating oil, (*b*) aniline, (*c*) turpentine by means of the bulb tube.

(2) Determine the coefficient of cubical expansion of glycerine with the specific gravity bottle.

(3) Find the expansion of glycerine by Matthiessen's method.

(4) Measure the absolute and apparent expansion of mercury by the weight thermometer.

(5) Given the coefficient of expansion of mercury between 0° and 100° C., determine the coefficient of expansion of the glass of the given piece of tube between the same limits.
(B.Sc. Pass Lond. 1900.)

(6) Measure the coefficient of expansion of a liquid by the weight thermometer method. (B.Sc. Pass Lond. 1891.)

(7) Determine the capacity of the bulb of the thermometer in terms of that of a centimetre of the stem.
(B.Sc. Pass Lond. 1892.)

(8) Calibrate a given bulb and tube and use it to find the expansion of water between two given temperatures, the expansion of the bulb being given. (Int. Sci. Hons. Lond. 1894.)

(9) Determine the expansion of water between two temperatures by weighing it in a solid of given expansion.
(Int. Sci. Hons. Lond. 1895.)

(10) Find the expansion of water through a given range of temperature by a dilatometer with given expansion coefficient.
(B.Sc. Hons. Lond. 1896.)

(11) Find the expansion of a glass rod given a steam jacket and microscope and then find the expansion of water between two temperatures by weighing some of the rod in water.
(B.Sc. Hons. Lond. 1896.)

(12) Blow a bulb of small bore and measure the ratio of the capacity of the same to that of each centimetre length of the stem. (Int. Sci. Hons. Lond. 1897.)

(13) Determine the coefficient of expansion of paraffin oil.
(Int. Sci. Hons. Lond. 1897.)

(14) Fill a water thermometer and use it to determine the maximum density of water. Plot the observations on a curve and determine the temperature at which water has the same coefficient of expansion as that of the given specimen of glass.
(Int. Sci. Hons. Lond. 1898.)

(15) Measure the expansion of the given liquid by a weighing method. (Int. Sci. Hons. Lond. 1898.)

(16) Find the coefficient of expansion of the given volatile liquid.

(17) Find the coefficient of expansion of the given liquid by weighing a solid in it at given temperatures.

(Int. B.Sc. Pass Lond. 1908.)

(18) Find the coefficient of expansion of the given liquid with a thermometer tube. (Ext. B.Sc. Pass Lond. 1908.)

(19) Find the density of water at 0° C., 8° C., and 12° C. with a glass sinker. (Ext. B.Sc. Hons. Lond. 1908.)

(20) Determine the expansion of water between 20° and 80° by means of a weight thermometer.

(Int. B.Sc. Pass Lond. 1909.)

(21) Construct a weight thermometer containing sufficient mercury to counterbalance the expansion of the glass. Determine the density of water by it at a series of different temperatures, using your results to find the temperature of maximum density. (Int. B.Sc. Hons. Lond. 1909.)

(22) Determine the density of the given liquid by weighing a solid of given density in it. (Ext. B.Sc. Pass Lond. 1909.)

(23) Find the maximum density point of water.

(Ext. B.Sc. Hons. Lond. Chemistry, 1909.)

(24) Determine the number of scale divisions in the bulb of the given dilatometer, and find the coefficient of expansion of the given liquid between about 15° C. and 25° C.

(Ext. B.Sc. Pass Lond. 1910.)

(25) Find the contraction when solutions of various percentages of salt in water are made.

(Int. B.Sc. Pass Lond. 1911.)

(26) Determine the mean coefficient of expansion of water between given limits, having given the coefficient of expansion of a glass sinker. (Board of Education, 1909.)

(27) Make a weight thermometer and determine the mean coefficient of cubical expansion of the given liquid between the two given temperatures. The coefficient of cubical expansion of glass is 0.000026. (Board of Education, 1906.)

(28) Make a weight thermometer from the given sample of glass-tubing. Fill the thermometer with mercury and find the coefficient of expansion of glass. Now use the thermometer to determine the absolute expansion of glycerine.

(29) Determine by Dulong and Petit's method the coefficient of expansion of glycerine between the limits 0° C. and 120° C.

(30) Cool some turpentine to 0° C. and place it in a graduated cylinder reading to $\frac{1}{10}$ c.c. Drop in some dry ice, which will sink to the bottom, and again note the volume, thus finding the volume of ice added. Allow the ice to melt, again read the volume, and calculate the volume of water formed. From your results determine the ratio of the densities of ice and water.

(31) Determine the apparent cubical coefficient of expansion in glass of the following:

(*a*) 20 % solution of $CaCl_2$;
(*b*) 10 % solution of NaCl;
(*c*) 20 % H_2SO_4.

CHAPTER V.

EXPANSION OF GASES.

In finding the relation between the three variables of a gas, viz. (1) the pressure (p), (2) the volume (v), (3) the temperature (t), experiments may be arranged to determine :

(i.) The relation between the pressure of the gas and its volume when the temperature is constant. (Boyle's law.)

(ii.) The relation between the volume and the temperature, the pressure being constant. (Charles's law.)

(iii.) The relation between the pressure and the temperature, the volume remaining constant.

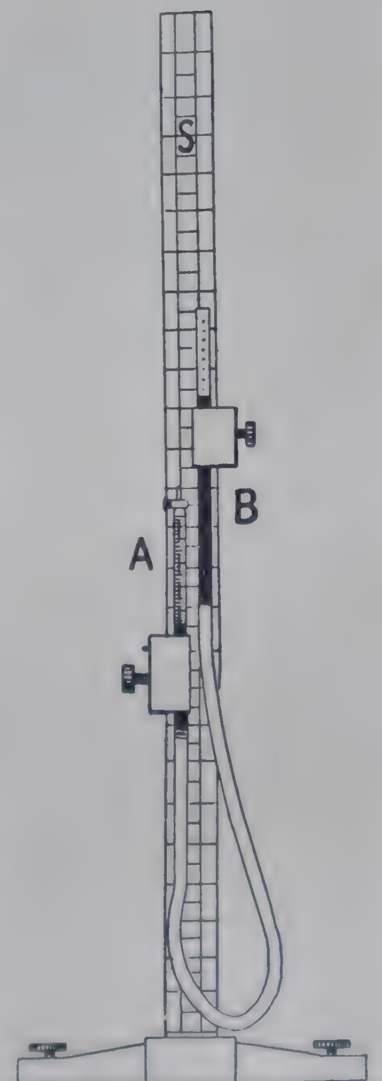

FIG. 27.—Apparatus to prove Boyle's law.

23. Experiment to prove Boyle's law.

Boyle's law states that at constant temperature the volume of a gas varies inversely as the pressure on it, or

pressure × volume = a constant.

Apparatus.—A burette A (Fig. 27) contains the air to be experimented on, and is connected by means of indiarubber pressure tubing, with an

open glass tube B. The pressure tube and part of B are filled with mercury, the pressure of which is measured by the metre scale S. The tubes A and B can be held in any position of the wooden stand by means of screw clamps.

(*a*) Fill the tube A with dry air as follows: First open the burette tap and raise the tube B until all the air has been expelled. Close the tap and connect to it a tube filled with dry calcium chloride. Lower the tube B and open the burette tap when a supply of dry air will be drawn into the burette. Now close the tap and take away the calcium chloride tube.

(*b*) Arrange the tubes A and B so that A is as low down as possible, the mercury in each of them being at exactly the same height. The air in A is now at the pressure of the atmosphere. Read the volume of air (V) in the burette to 0.1 c.c. Read the height of the barometer (H) and note the temperature of the room.

(*c*) Raise B till the mercury is about 5 cms. *higher* than that in A. Read the difference in level (h) of the mercury columns by means of the scale S. The air is now under a pressure greater than that of the atmosphere, and this pressure $= H + h$. Also read the volume of air in A.

(*d*) Keeping A stationary raise B so that the difference in level of the mercury columns is about 10 cms. Read the volume and pressure again. Repeat these observations at intervals of 5 cms. of difference in level until B has reached the top of the stand.

(*e*) Bring the tube B to the bottom of the scale and raise the tube A so that the mercury in B is about 5 cms. *lower* than that in A. Read this difference of level (h) and the pressure will now be $(H - h)$ since it is less than that of the atmosphere. Read the volume of air in the burette.

(*f*) Keeping B fixed, raise the tube A 5 cms. at a time and repeat the observations in (*e*) until A is at the top of the stand. Read the temperature of the air when the experiment is concluded.

(*g*) Enter results thus:

Temperature of room at beginning of experiment $= 14^\circ.6$ C.
" " end " $= 15^\circ.1$ C.
Height of barometer (H) $= 74.3$ cms.

Volume of air in A. (V).	Height of mercury in B.	Height in A.	Difference in level =(h).	Total pressure, P=H±h.	Pressure × volume, =P×V.
8.38	36.1	36.1	0.0	74.3	622.6
7.83	42.4	37.4	5.0	79.3	620.7
7.41	48.4	38.6	9.8	84.1	623.1
......	......	......	......	......	......
......	......	......	......	......	......
......	......	......	......	......	......

(*h*) Plot a curve with volumes (V) as abscissae and total pressures (P) as ordinates.

This *isothermal*, as the curve (Fig. 28) is called, belongs to the class of curves known as rectangular hyperbolae, the equation to which is $xy=$constant.

Figs. 29 and 30 represent forms of apparatus suitable for pressures above atmospheric pressure, while that in Fig. 31 has a closed graduated tube for the gas.

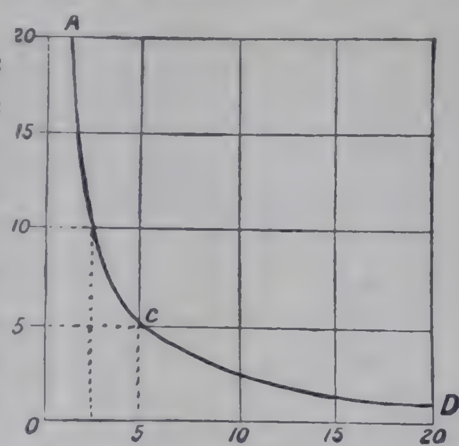

FIG. 28.—Curve for Boyle's law.

24. Determination of the relation between the volume and temperature of a gas at constant pressure (Charles's law).

Charles's law states that the volume of a gas increases by $\frac{1}{273}$ when the temperature is raised through 1° C., the pressure being constant.

Here the object of the experiment will be to find the coefficient of expansion at constant pressure in the case of air.

First method.—*Apparatus* (Fig. 32).—A piece of barometer tubing A of uniform bore and about 70 cms. in length. The tube is closed at one end and carefully filled with dry air, while the other end of the tube is plugged with a thread of

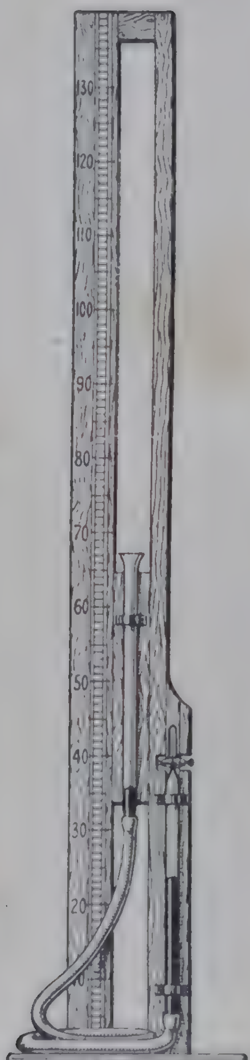

FIG. 30.

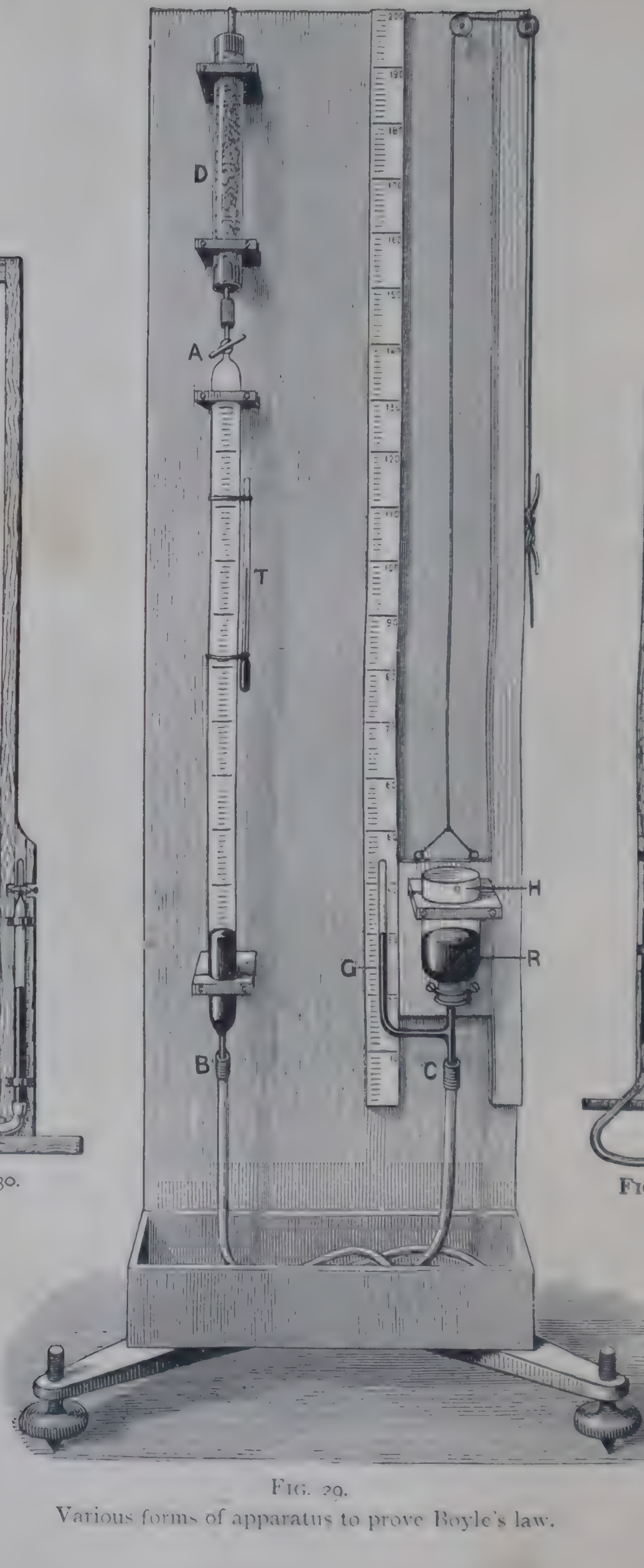

FIG. 31.

FIG. 29.
Various forms of apparatus to prove Boyle's law.

mercury B which serves to enclose the volume of air in the tube. The plug is placed about half way down the tube.

A thermometer T is fixed to the tube by means of a fine wire and the whole is placed in a wide glass tube C, through which steam or hot water may be passed. The outer tube rests loosely in slots made in the wooden uprights E, E.

FIG. 32.—Apparatus to prove Charles's law.

(*a*) Tap the tube C in order to prevent the mercury thread from sticking. Read the temperature on the thermometer ($t_1°$) and with a metre scale measure the distance from the closed end of the tube to the inner edge of the thread of mercury. If the bore is uniform this length will be proportional to the volume of air enclosed in the tube. Call the length (v_1).

(*b*) Fit up a flask with a steam tube and connect it to the apparatus. Pass steam through the tube C for ten minutes and after tapping the tube, again read the temperature ($t_2°$), and length (v_2) of the column of air.

(*c*) Calculate the coefficient from your results.

The coefficient of expansion *i.e.* the expansion of unit volume for a rise in temperature of 1° Centigrade will be given by :

$$a = \frac{v_2 - v_1}{v_1(t_2 - t_1)}.$$

e.g.

$$v_1 = 50.6,$$

$$v_2 = 65.7,$$

$$t_1 = 18°.4,$$

$$t_2 = 99°.7\ ;$$

$$\therefore \quad a \text{ (calculated)} = 0.00367.$$

This method works well if a tube is used which is calibrated into portions of equal length. The trouble is to prevent moisture entering the tube and so making the expansion too great.

(*d*) Plot the results obtained above, on squared paper, taking the volumes for abscissae and temperatures for ordinates; connect the two points so obtained by means of a straight line and produce this on to the axis representing temperature, and find the temperature corresponding to $v=0$, *i.e.* the temperature at which the volume of the gas would disappear.

This temperature is known as the *absolute zero*, and is about $-273°$ C. Temperatures measured on the *absolute scale* are obtained by adding 273 to the ordinary Centigrade readings.

Second method.—*Apparatus.*—A glass sample tube (Fig. 33), of about 250 c.cs. capacity and having a stopcock at either end.

FIG. 33.—Glass sample tube for the determination of the expansion of air at constant pressure.

This form is best to ensure quickness of drying by blowing air through. Otherwise a similar tube rounded off at one end and with a stopcock at the other may be used. A round-bottomed flask fitted with a rubber stopper will also serve. In the latter case a glass stopcock is pushed through the stopper.

(*a*) Dry the tube by blowing air through and find its weight (W_1).

(*b*) After closing the lower cock and opening the upper one, support the tube vertically in a vessel containing boiling water. To prevent steam condensing and dropping inside the tube, a piece of rubber tubing can be slipped on the open end.

(*c*) After the tube has been immersed for five minutes, note the temperature ($t°$), close the stopcock and immerse the tube in a vessel containing cold water. Add lumps of ice until the temperature of the water is 0° C. Then open the lower stopcock when the air, which has contracted on cooling to 0° C., will cause the water to rush in and partially fill the tube. Now holding the tube with a cloth so as not to heat it, gradually raise it until the water is at the same level inside and out, *i.e.* the air is again at the pressure of the atmosphere.

(*d*) Close the stopcock, and remove the tube from the vessel. Dry the outside and find the weight (W_2) of the tube and the enclosed water.

(*e*) The weight of water required to fill the whole of the tube is found by immersing it in a tank containing water free from air and, after completely filling the apparatus, closing both stop-cocks and obtaining the weight (W_3) of the tube and contents.

(*f*) Since one gram of water $= 1$ c.c.
Total volume of air in tube $= (W_3 - W_1)$ c.c.
Volume of air expelled $= (W_2 - W_1)$ c.c.
$\therefore$ (By subtraction) vol. of air remaining after expansion $= (W_3 - W_2)$ c.c.

$\therefore$ $(W_3 - W_2)$ c.c. of air have expanded by $(W_2 - W_1)$ c.c. for a rise in temperature of $t°$.

$\therefore$ coefficient of expansion of air at constant pressure

$$\alpha = \frac{W_2 - W_1}{(W_3 - W_2)t}.$$

e.g.

$$W_1 = 93.4 \text{ grams},$$
$$W_2 = 153.3 \text{ grams},$$
$$W_3 = 316.5 \text{ grams},$$
$$t = 99°.7,$$
$$\alpha \text{ (calculated)} = 0.00368.$$

25. To determine the relation between the pressure and temperature of air when its volume is kept constant.

Apparatus.— Jolly's apparatus, which consists of a glass bulb A (Fig. 34), about 300 c.cs. capacity, connected by a short horizontal tube with the Boyle's tubes B and C. The tube B is fixed, but C can be moved up and down a slot in the wooden stand. (The horizontal tube may be fitted with a tap to adjust the pressure in the apparatus to that of the air. Above the tap may also be arranged a tube filled with soda-lime and calcium chloride, so as to free the incoming air from moisture and CO_2.)

In order to raise the temperature of the air in A, a copper water tank D is fixed by a metal flange to the wooden partition E, which serves to screen the mercury column in B and C from any direct heating effect. A metal pillar F let into the wooden

base of the piece of apparatus serves to support a large rose burner, while the temperature of the tank is measured by the thermometer T. Between B and C is a wooden metre scale for measurement of the height of the mercury column.

(*a*) Carefully read and note the height of the barometer (H).

(*b*) Adjust the tube C so that the mercury in B is near the top of the tube and at a certain height on the metre scale. Note this mark, and also note the height of the mercury in C, and thus obtain the difference in level (h). The total pressure is ($H \pm h$). If the mercury in C is lower than that in B the pressure is $H - h$.

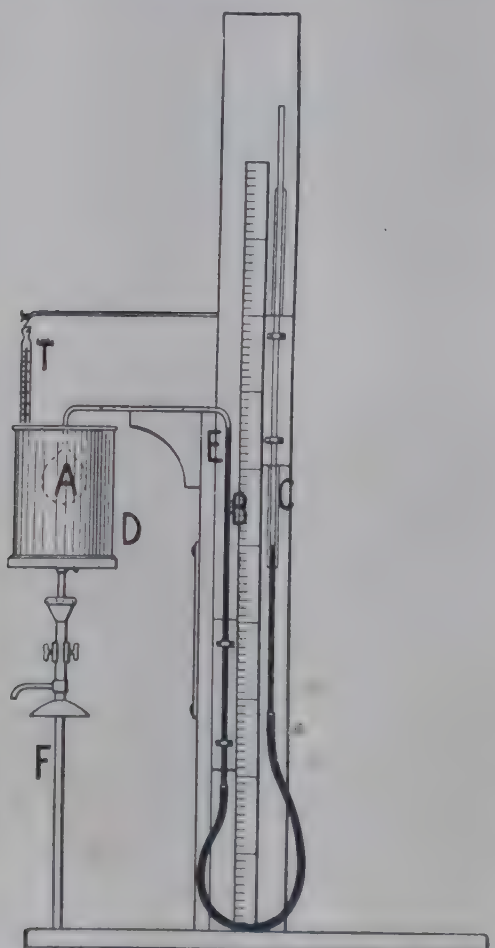

FIG. 34.—Apparatus to determine the expansion of air at constant volume.

(*c*) Fill the tank with water, stir well, and read the temperature (t).

(*d*) Heat the water in the tank until the temperature of the water, and therefore of the air in the bulb A, has been raised about 5°. Take the burner away, stir well, and note the exact temperature reading to $\frac{1}{10}$°.

(*e*) Adjust the mercury in C by raising it until the gas has decreased to its original volume, *i.e.* until it has reached the fixed mark on the scale. Note the position of C, and the position of B being the same as before, calculate the difference in level and the total pressure.

(*f*) Repeat the observations at intervals of 5° until the boiling point of water is reached. If higher temperatures are required, the water may be replaced by glycerine.

Enter results thus :

Height of Barometer (H)=75.5 cms.

Experiment.	Position of mercury in C.	Position of mercury in B.	Difference of level = C − B = h.	Total pressure P = H + h.	Temperature of enclosure (t).
1.	69.0 cms.	63.0 cms.	6.0 cms.	81.5 cms.	14°.2
2.	70.4		7.4	82.9	19 .1
3.	71.3		8.3	83.8	23 .0
4.	72.8		9.8	85.3	28 .5
......	......		......	......	......
......	......		......	......	......
......	......		......	......	......

(g) Plot a curve with pressures as ordinates and temperatures as abscissae.

(h) Take two or three pairs of observations of the total pressure (P) and the corresponding temperature (t), and calculate the coefficient of increase of pressure of air at constant volume.

Errors are produced as follows : (1) The temperature of the air in A is slightly different from that in the horizontal connecting tube. Since the volume of the air in the tube is only small compared with that in the bulb A, this error is not large ; (2) the glass bulb expands on heating. The expansion of glass is slight, however, compared with that of air.

26. Air thermometers.

It is evident that by taking observations of the pressure the temperature of the bulb corresponding to that pressure can be deduced from the curve obtained in Expt. 25. Hence the apparatus can be used as an air thermometer, and such an instrument will give more accurate readings than a mercury thermometer, because the thermal expansion of the gas is very great compared with the expansion of the containing vessel.

27. Characteristic equation of a gas.

If the pressure, volume and temperature of a gas are all allowed to vary simultaneously, the equation connecting the three variables is $pv = \mathrm{R}.\mathrm{T}$ where T is the absolute temperature and R is a constant. This characteristic equation may be verified by the apparatus used in Expt. 25.

Note on Chapter V.

Messrs. A. Gallenkamp & Co., of Finsbury, E.C., make a form of constant pressure apparatus which has certain advantages

over that shown in Fig. 32. The air is enclosed in a U-tube, one limb of which is graduated, while the other is open to the atmosphere. The volume of air under test is enclosed by means of a quantity of sulphuric acid round the bend of the tube, and the constant pressure is obtained by running off through a tap fitted to the lower end the excess of acid until the level of liquid in the two limbs is the same. The apparatus is heated by a water jacket, through which passes a steam coil made of copper.

Additional Exercises.

1. Find the coefficient of increase of pressure of a constant volume of air with rise of temperature.

2. Determine the temperature of boiling water with an air thermometer, using melting ice to fix the zero point.
(B.Sc. Pass Lond. 1893.)

3. Make a barometer and, admitting a bubble of air, calculate the correction required in consequence at 28 inches, 29 inches and 30 inches respectively.

4. Given a long uniform tube closed at one end, introduce a short column of mercury and graduate as a thermometer. The readings being assumed correct at 0° give a graphical table of temperature corrections on curve paper.
(B.Sc. Hons. Lond. 1895.)

5. Find the expansion of air at constant pressure between two temperatures by observing the movement of a mercury index along a uniform fine bore tube open at one end.
(Int. Sci. Hons. Lond. 1896.)

6. Compare a mercury and an air thermometer.
(B.Sc. Pass Lond. 1897.)

7. Measure the volume of the given flask at the temperature of the room and at 80° C. (B.Sc. Pass Lond. 1899.)

8. Plot the relation between the pressure and volume of gas in a given glass vessel and determine its deviations from Boyle's law. (B.Sc. Pass Lond. 1900.)

9. Compare the given mercury and air thermometers.
(B.Sc. Hons. Lond. 1900.)

10. Find the coefficient of expansion of air at constant pressure. (Ext. B.Sc. Pass Lond. 1908.)

11. Compare the volumes between successive marks in a tube of irregular bore, using a Boyle's tube method.
(Ext. B.Sc. Pass Lond. 1909.)

CHAPTER VI.

CALORIMETRY AND SPECIFIC HEAT.

Calorimetry deals with the measurement of the *amount* of heat, which has the same relation to *temperature* as (*a*) the quantity of a gas compared with the pressure on it, or (*b*) the quantity of water in a reservoir compared with the 'head' of the water.

The amount of heat in a substance depends on:

i. The mass of the substance.
ii. Its temperature.
iii. Its capacity for heat.

28. Quantity of heat.

Apparatus.—Beakers, two Centigrade thermometers, heater.

(*a*) Weigh out 100 grams of cold water in a beaker, and note its temperature ($t_1°$).

(*b*) Weigh out 100 grams of water into a similar beaker, and heat the water until the temperature is about 50° C., as measured by a second thermometer.

(*c*) After stirring the hot water note the exact temperature ($t_2°$), and then, holding the beaker with a cloth, pour the contents into the cold water, stir well, and note the temperature of the mixture ($t_3°$).

(*d*) The heat gained by cold water

$$= \text{mass} \times (\text{rise in temperature})$$
$$= 100(t_3 - t_1).$$

Heat lost by hot water

$$= \text{mass} \times (\text{fall in temperature})$$
$$= 100(t_2 - t_3).$$

On calculating, it will be noticed that the gain of heat is rather less than the loss, owing to some heat being required to heat the beaker.

The amount of heat required to raise the temperature of 1 gram of water 1° C., or the amount of heat given out by 1 gram of water when the temperature falls through 1° C. is the unit employed in calorimetry. This unit is known as a *calorie* or *therm*.

29. Capacity for heat.

Apparatus.—Beakers, two Centigrade thermometers, mercury, iron filings, test tubes, heater.

(*a*) Take two similar beakers and weigh out into each 100 grams of cold water. Place a thermometer in each, and note the temperatures.

(*b*) Take two similar test tubes, and into one place 50 grams of iron filings, while into the other weigh out 50 grams of mercury.

(*c*) Place the two test tubes side by side into a tank of boiling water, or better, into a steam heater.

(*d*) After the test tubes and contents have been heated for 5 minutes, quickly transfer the iron filings into the first beaker, stir well, and note the temperature of the mixture. Now take the other test tube out of the heater and pour the mercury quickly into the second beaker, and, as before, note the temperature.

It will be noticed that the rise in the temperature in the case of the beaker containing the iron filings is nearly three times that produced in the second beaker by the mercury. This experiment shows that equal masses of different substances at the same temperature may possess different amounts of heat, or, in other words, they have different capacities for heat.

The thermal capacity of a substance may be defined as the amount of heat required to raise its temperature 1° C. If unit mass of the substance is taken the thermal capacity represents what is termed the *specific heat*.

30. To determine the water equivalent of a calorimeter and thermometer.

The water equivalent of a substance is the mass of water which would require the same amount of heat as the substance to raise its temperature 1° C. If w is the mass of the body in grams and s is the specific heat of the body, the water equivalent is $w \times s$ grams.

In accurate calorimetric work the water equivalents of the calorimeter and the thermometer must be determined and these values added to the water equivalent of the liquid in the calorimeter.

(i.) **Water equivalent of calorimeter.**

Apparatus.—Copper calorimeter, Centigrade thermometer.

(*a*) Dry the calorimeter carefully and weigh it.

(*b*) Place a thermometer inside it and note the temperature registered ($t°$).

(*c*) Take some water at a temperature of about 40°. Note its temperature (T°) exactly and pour enough in the calorimeter to cover the bulb of the thermometer.

(*d*) Stir well and note the temperature of the contents ($t_1°$).

(*e*) Weigh the calorimeter and contents and thus obtain the weight of water used (W).

Then if C is water equivalent of the calorimeter, heat gained by calorimeter $= C(t_1 - t)$ units.

$$\text{Heat lost by water} = W(T - t_1).$$

$$\text{Heat lost} = \text{heat gained};$$

$$\therefore\ W(T - t_1) = C(t_1 - t);$$

$$\therefore\ C = \frac{W(T - t_1)}{t_1 - t}.$$

Water equivalent by calculation = mass of calorimeter × 0.093.

Since 0.093 is the specific heat of copper,

e.g.

$$W = 39.61 \text{ grams},$$
$$T = 44°.0,$$
$$t = 18°.2,$$
$$t_1 = 41°.7;$$
$$\therefore\ C = 3.84,$$

mass of calorimeter × 0.0933 = 3.49.

(ii.) **Water equivalent of thermometer.**

Apparatus.—Calorimeter, two Centigrade thermometers, heater.

(*a*) Weigh into the calorimeter enough cold water to cover the bulb of the thermometer. Note the weight of water (W) and its temperature ($t°$).

(*b*) Dip the thermometer into boiling water for about two minutes. Note the temperature of the water (T°).

(*c*) Quickly take the thermometer out of the boiling water and place in the calorimeter. Stir well and take the temperature of the contents ($t_1°$).

Then if

θ = water equivalent of thermometer,

C = water equivalent of calorimeter (by experiment 30. i.).

$$\text{Heat lost by thermometer} = \theta(T - t_1).$$

$$\text{Heat gained by water} = W(t_1 - t).$$

$$\text{Heat gained by calorimeter} = C(t_1 - t);$$

$$\therefore \quad \theta(T - t_1) = (W + C)(t_1 - t).$$

$$\theta = \frac{(W + C)(t_1 - t)}{T - t_1}.$$

e.g.

$$W = 43.20 \text{ grams},$$
$$C = 3.84 \text{ grams},$$
$$T = 100°.1,$$
$$t = 17°.9,$$
$$t_1 = 18°.8;$$

$\therefore \quad \theta$ (calculated) = 0.52.

31. Determination of specific heat of a solid by method of mixtures.

The specific heat of a substance is the amount of heat in calories required to raise the temperature of one gram of the substance through 1° C.

Thus, the specific heat of water is 1.
the specific heat of mercury is 0.033.
the specific heat of copper is 0.093.

In finding the specific heat of a solid a known mass of the substance is usually heated in a steam heater to about 100° C.

and then dropped into a known mass of water contained in a calorimeter. The rise of temperature is noted, and from these data the specific heat may be determined.

Errors in the observations may arise because:

(1) The calorimeter and thermometer gain heat along with the water.

(2) The substance may lose heat while being transferred to the calorimeter.

(3) The calorimeter and contents lose heat by radiation while the experiment is proceeding.

Corrections must be made for these errors, if the results are to be accurate.

Apparatus.—Calorimeter, Centigrade thermometer, enclosure, piece of metal, steam heater.

The steam heater consists of a hollow copper cylinder (Fig. 35) 10 inches long and 2 inches diameter, surrounded by a metal steam jacket, the outside diameter being $3\frac{1}{2}$ inches. The inside cylinder is closed at the top with a cork through which the thermometer passes. The lower end is closed with a sliding metal disc which can be moved so as to allow the substance to drop into the calorimeter. The steam heater is packed round the outside with green baize and bound to a teak board by means of metal hoops. Metal tubing connects the steam jacket with a small steam boiler.

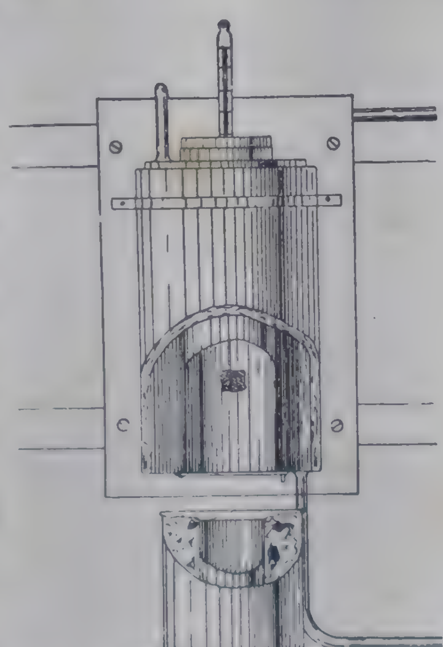

FIG. 35.—Steam heater used in the determination of specific heats.

The calorimeter is best made of spun copper about $\frac{1}{32}$ inch in thickness and about 4 inches in height and $2\frac{1}{2}$ inches diameter. Soldered calorimeters are unsatisfactory.

During the experiment the calorimeter is placed in a metal enclosure containing cotton wool in order to prevent heat lost by radiation from the sides of the calorimeter.

A better method of protecting the calorimeter is to place it in

a double-walled metal enclosure, the space between the two walls being filled with water at the temperature of the room.

(*a*) Weigh the piece of metal, the specific heat of which is to be determined. Thus find (m).

(*b*) Suspend the metal by a fine thread in the steam heater so that it is near the bulb of the thermometer.

(*c*) Arrange the steam supply, and while the substance is being heated weigh the empty calorimeter (w). Fill it half full of water; weigh again and find the weight of water in the calorimeter (W).

(*d*) When the metal has been in the heater for about twenty minutes note the temperature of the metal (T°) and that of the cold water in the calorimeter ($t_1°$).

(*e*) Place the calorimeter under the heater, quickly pull the sliding disc, and lift the cork so as to release the thread and allow the substance to drop into the calorimeter.

(*f*) Take the calorimeter away, stir well, and note the highest temperature ($t_2°$) of the mixture.

(*g*) Calculate the results thus:

Let S = specific heat of metal.

Heat lost by metal $= m \,.\, S \,.\, (T - t_2)$,
Heat gained by water $= W(t_2 - t_1)$,
Heat gained by calorimeter $= w \times 0.093 \times (t_2 - t_1)$,
Heat gained by thermometer $= \theta \times (t_2 - t_1)$,

where θ is the water equivalent of the thermometer. For most thermometers $\theta = 0.5$.

Heat lost = heat gained.

$$m \,.\, S \,.\, (T - t_2) = (W + 0.093w + \theta)(t_2 - t_1).$$

$$S = \frac{(W + 0.093w + \theta)(t_2 - t_1)}{m(T - t_2)}$$

(W + w)(t -

e.g.

$W = 63.03$ grams,
$m = 83.07$ grams,
$w = 31.83$ grams,
$t_1 = 17°.6$,
$t_2 = 26°.2$,
$T = 99°.6$,
$\theta = 0.5$;

$\therefore$ S (calculated) $= 0.0938$.

m S (T - t) = (W + w)(t₂ - t)

32. Accurate determination of specific heat of a solid by the method of mixtures.

During the conduction of an experiment of the specific heat of a substance by the method of mixtures the calorimeter and contents are losing some of their heat by means of radiation from the surface of the calorimeter. The loss of heat due to cooling can be observed by noticing the temperature of the calorimeter every half minute while the experiment is going on, and after this loss has been deduced from these observations the corrected final temperature of the mixture can be calculated.

Apparatus.—As in Experiment 31.

(*a*) Take a piece of the solid and weigh it.

(*b*) Place it in the steam heater for about half an hour until its temperature has risen to about 100° C.

(*c*) Fill a calorimeter about half full of water and place it in the enclosures. Stir the water constantly and note its temperature every half minute for about six minutes.

(*d*) After the twelfth reading has just been taken quickly introduce the solid into the calorimeter, and be in time to take the thirteenth reading at the next half minute. Stir and take readings every half minute on the calorimeter until the temperature is just falling.

(*e*) Now take readings every half minute while the calorimeter is cooling for about six minutes.

(*f*) Weigh the calorimeter and water, and, knowing the weight of the calorimeter, find the weight of the water.

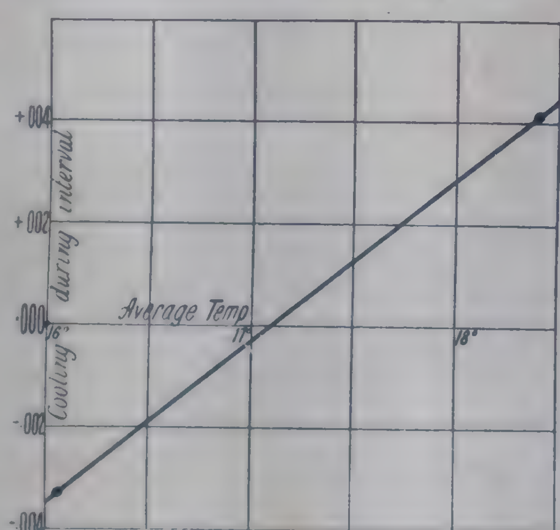

FIG. 36.—Curve of cooling for a calorimeter.

(*g*) From the above observations of (c) and (e) we can find the rate of cooling of the calorimeter and so draw a curve of

cooling (see Fig. 36) from which we can find the cooling correction for all the temperatures observed.

The following example will illustrate the method :

1. Time (minutes.)	2. Temperature.	3. Average Temperature.	4. Cooling during interval.	5. Total Cooling.	6. Corrected Temperature.
0.0	16.04	*Cooling during interval.*			
0.5	16.05	$16.04 - 16.06 = -0.02$			
1.0	16.05	$16.05 - 16.07 = -0.02$			
1.5	16.05	$16.05 - 16.07 = -0.02$			
2.0	16.06	$16.05 - 16.07 = -0.02$			
2.5	16.06	$16.06 - 16.08 = -0.02$			
3.0	16.06	$16.06 - 16.08 = -0.02$			
3.5	16.07	Mean $= -0.02$			
4.0	16.07				
4.5	16.07	Cooling for 1′ interval $= -\frac{0.02}{6} = -0.0033$.			
5.0	16.08	∴ Average temperature $= 16°.06$.			
5.5	16.08				
6.0	Substance	introduced.			
6.5	17.40	16.74	−0.001	−0.001	17.40
7.0	17.60	17.50	+0.001	0.000	17.60
7.5	17.85	17.72	+0.002	+0.002	17.85
8.0	18.06	17.96	0.003	0.005	18.07
8.5	18.20	18.13	0.003	0.008	18.21
9.0	18.28	18.24	0.003	0.011	18.29
9.5	18.31	18.29	0.004	0.015	18.33
10.0	18.38	18.35	0.004	0.019	18.40
10.5	18.39	18.38	0.004	0.023	18.41
11.0	18.40	18.39	0.004	0.027	18.43
11.5	18.41	18.41	0.004	0.031	18.44
12.0	18.42	18.42	0.004	0.035	18.46
12.5	18.42	18.42	0.004	0.039	18.46
13.0	18.42	18.42	0.004	0.043	18.46
13.5	18.42	18.42	0.004	0.047	18.47
14.0	18.42	18.42	0.004	0.051	18.47
14.5	18.41	18.41	0.004	0.055	18.47
15.0	18.40	18.40	0.004	0.059	18.46
15.5	18.40	18.40	0.004	0.063	18.46
16.0	18.40	18.40	0.004	0.067	18.47
16.5	18.40	18.40	0.004	0.071	18.47
17.0	18.39	18.39	0.004	0.075	18.47
17.5	18.39	18.39	0.004	0.079	18.47
18.0	18.38	18.38	0.004	0.083	18.47
18.5	18.38	18.38	0.004	0.087	18.47
19.0	18.38	18.37	0.004	0.091	18.46

Cooling during last interval.

18.42 − 18.40 = 0.02
18.42 − 18.39 = 0.03
18.41 − 18.39 = 0.02
18.41 − 18.38 = 0.03
18.40 − 18.38 = 0.02
18.40 − 18.37 = 0.03

Mean = +0.025

Cooling for 1 interval = +0.0041.
Average temperature = 18°.40.

The figures in column 4 are obtained from the curve of cooling (Fig. 36) taking average temperature as abscissae and cooling for one interval as ordinates. The figures in column 6 are obtained by adding together those in columns 2 and 5.

Corrected final temperature of substance = 18°.47.

The specific heat is calculated as usual thus :

Weight of water + calorimeter = 177.84 grams.
Weight of calorimeter = 26.43
Weight of water = 151.41

Weight of substance = 28.11 grams.
Initial temperature of substance = 98°.3.
Initial temperature of water = 16°.08.
Final temperature of substance = 18°.47.
Water equivalent of thermometer = 1.0.
Water equivalent of calorimeter and stirrer (calculated) = 2.61. 151·41

Total water equivalent = 155 grams. 155·02

Specific heat of substance

$$= \frac{\text{total water equivalent} \times \text{rise in temperature of water}}{\text{weight of substance} \times \text{fall in temperature of substance}}$$

$$= \frac{155.02 \times 2.39}{28.1 \times 79.83}$$

$$= 0.164.$$

Fig. 37 represents the observed and corrected temperatures for each interval during which the substance was in the calorimeter.

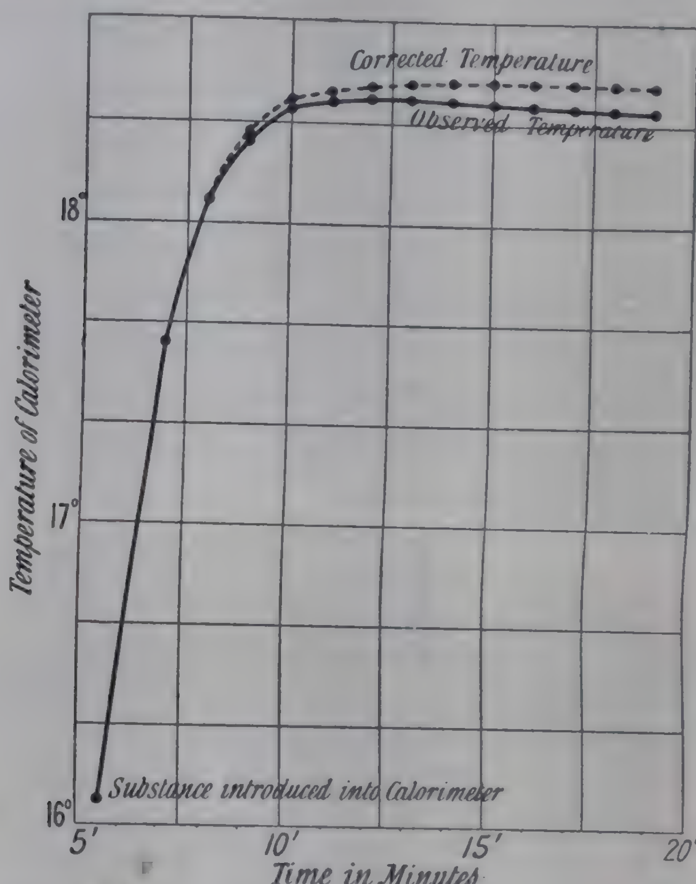

FIG. 37.—Curve showing the observed and corrected temperatures of a calorimeter.

33. Measurement of high temperatures by the calorimetric method.

To measure the temperature of the blowpipe flame.

Apparatus.—Large calorimeter (capacity about 500 c.c.), thermometer, brass cylinder,* tripod, blowpipe (Fig. 38).

(*a*) Weigh the brass cylinder. Call this weight (m).

(*b*) Weigh the large copper calorimeter and calculate the

* A brass disc about 3 inches diameter and $\frac{1}{4}$ inch thick with a hole of $\frac{1}{2}$ inch diameter drilled out the centre will serve well for the experiment. If the cylinder is too thick, *e.g.* a brass weight, then the sudden contraction of the outer layer of metal when immersed in the water forces out the softer hot metal inside and causes metallic beads to form on the surface.

water equivalent by multiplying together its mass and its specific heat (0.093). Let C = water equivalent.

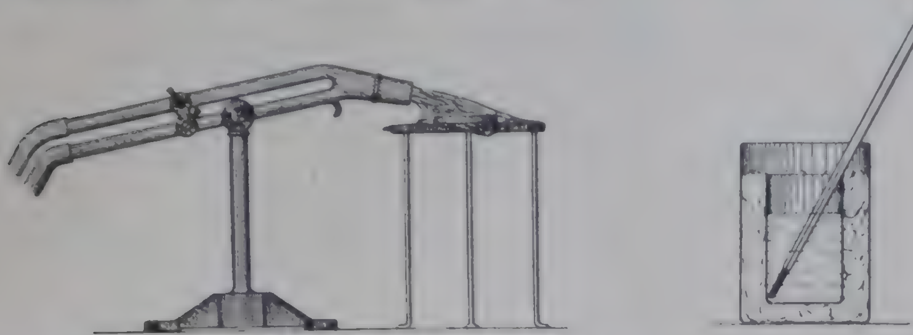

FIG. 38.—Apparatus for the determination of high temperatures by the calorimetric method.

(*c*) Fill the calorimeter half-full of water and weigh again on a flat pan balance. Subtract the weight of the empty calorimeter and thus find the weight of water (W). Note the temperature of the cold water (t°).

(*d*) Place the brass cylinder on a pipe-clay triangle on top of a tripod and heat it to a bright red heat in the blowpipe flame. At the end of a quarter of an hour we may assume the temperature of the cylinder is fairly constant. Grasp the heated metal with a pair of crucible tongs and quickly place it in the calorimeter. Stir well with the thermometer and note the temperature of the mixture t_1°.

Then if T° = temperature of flame,

Heat lost by brass cylinder $= m \times 0.094 \times (T - t_1)$.

[0.094 = specific heat of brass.]

Heat gained by water + calorimeter $= (W + C)(t_1 - t)$.

$$\therefore \quad 0.094\, m(T - t_1) = (W + C)(t_1 - t).$$

$$T = \frac{(W + C)(t_1 - t)}{0.094\, m} + t_1.$$

e.g.

$$m = 145.1 \text{ grams,}$$
$$W = 269.1 \text{ grams,}$$
$$C = 105.5 \times 0.093 = 9.76 \text{ grams,}$$
$$t = 12^\circ.5,$$
$$t_1 = 55^\circ.1\ ;$$

$\therefore$ T (calculated) $= 926^\circ$.

Note.—The cylinder should be cleaned with a file and sandpaper before use.

34. Determination of the specific heat of a liquid by the method of mixture.

This method may be used in the case of liquids which, when mixed with water, give no absorption or evolution of heat, *e.g.* turpentine or glycerine.

Apparatus.—Calorimeter, enclosure, glycerine or turpentine, beaker, two Centigrade thermometers.

(*a*) Dry and weigh the calorimeter. Fill it about one-third full of the liquid and weigh again. Note the weight of the liquid (w_1). Note its temperature ($t_1°$).

(*b*) Boil some water in a beaker, note its temperature (t_2), and pour it into the calorimeter until the latter is two-thirds full. Take the temperature of the mixture ($t°$) when the mercury column is steady.

(*c*) Weigh the calorimeter and contents, and by subtracting the weight of calorimeter + liquid obtain the weight of water added (w_2).

Then if s = specific heat of liquid

$$\text{Heat lost by water} = w_2(t_2 - t)$$

$$\text{Heat gained by liquid} = w_1 s(t - t_1)$$

$$\text{Heat gained by calorimeter and thermometer} = (c + \theta)(t - t_1)$$

where c and θ are the respective water equivalents.

$$\therefore \; w_1 s(t - t_1) + (c + \theta)(t - t_1) = w_2(t_2 - t)$$

$$w_1 s(t - t_1) = w_2(t_2 - t) - (c + \theta)(t - t_1)$$

$$\therefore \; s = \frac{w_2(t_2 - t) - (c + \theta)(t - t_1)}{w_1(t - t_1)}.$$

e.g. for glycerine :

$$w_1 = 83.22 \text{ grams},$$
$$t_1 = 15°.9$$
$$t_2 = 68°.8,$$
$$t = 33°.3,$$
$$w_2 = 25.19 \text{ grams},$$
$$c = 3.5 \text{ grams},$$
$$\theta = 0.6 \text{ gram};$$
$$\therefore \; s \text{ (calculated)} = 0.569.$$

35. Determination of the specific heat of a liquid having given the specific heat of a solid.

Apparatus.—Liquid, piece of brass, calorimeter, steam heater.

(*a*) Weigh the calorimeter empty, then fill it one-third full of the liquid to be tested and weigh again. This gives the weight of the liquid used (M).

(*b*) Weigh the piece of brass (m).

(*c*) Place the brass in the heating apparatus and keep it in for about half an hour. Take its temperature by means of the thermometer inside (T°). At the same time note the temperature of the liquid in the calorimeter (t_1°).

(*d*) Take the calorimeter and contents to the lower part of the heating apparatus, pull the slide and quickly lower the piece of brass into the liquid. Stir well and take the temperature of the mixture when it has become steady. Call this temperature (t_2°).

(*e*) Calculate C the water equivalent of the calorimeter and thermometer by multiplying the weight of the calorimeter by its specific heat (0.093) and adding 0.5 for the water equivalent of the thermometer.

Then

Heat lost by the metal $= m \times 0.094 \times (\mathrm{T} - t_2)$ since specific heat of brass $= 0.094$

Heat gained by liquid of specific heat $\mathrm{S} = \mathrm{M} \times \mathrm{S} \times (t_2 - t_1)$

Heat gained by calorimeter and thermometer

$$= \mathrm{C} \times (t_2 - t_1);$$

$$\therefore \; m \times 0.094 \times (\mathrm{T} - t_2) = \mathrm{M} \times \mathrm{S} \times (t_2 - t_1) + \mathrm{C}(t_2 - t_1);$$

$$\therefore \; \mathrm{S} = \frac{m \times 0.094(\mathrm{T} - t_2) - \mathrm{C}(t_2 - t_1)}{\mathrm{M}(t_2 - t_1)}.$$

Repeat the experiment twice and take the mean of the results.

e.g. for turpentine:

$$\begin{aligned} \mathrm{M} &= 50.62 \text{ grams}, \\ m &= 83.07 \text{ grams}, \\ \mathrm{T} &= 99^\circ.4, \\ t &= 14^\circ.4, \\ t_2 &= 33^\circ.5, \\ \mathrm{C} &= 4.1 \text{ grams}; \end{aligned}$$

$$\therefore \; \mathrm{S}\text{ (calculated)} = 0.451.$$

36. Determination of the specific heats of liquids by the method of cooling.

If a given mass of liquid at a known temperature be placed in a vessel and allowed to cool in an enclosure at a lower temperature than its own, it is found that the loss of heat depends only upon :

(1) The temperature of the liquid.

(2) The temperature of the enclosure.

(3) The nature and extent of the surface at which cooling takes place.

The heat lost is independent of the nature of the liquids, so that if two liquids are allowed to cool under exactly similar conditions they will lose heat at the same rate.

We can determine the specific heat of a liquid by observing the time taken to cool from one temperature to another.

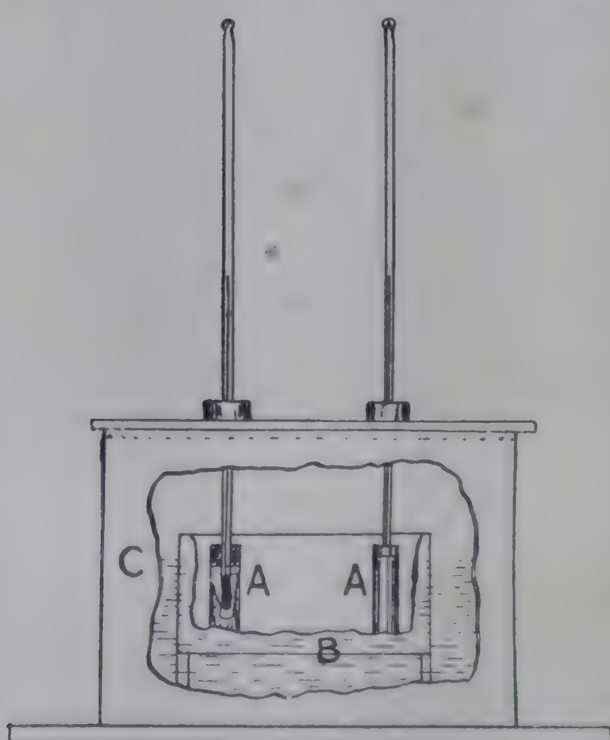

FIG. 39.—Apparatus for the determination of the specific heat of a liquid by cooling.

Apparatus. — Two aluminium calorimeters A, A (Fig. 39), each 2 inches high and $\frac{3}{4}$ inch diameter, and fitted with a cork through which passes a thermometer. During the experiment the calorimeters are placed in a zinc trough B resting on four supports, which are fixed to an outer zinc vessel C. The latter is provided with a wooden lid lined on the inside with felt or leather, and through which the two thermometers are passed. The space between B and C is filled with water, or better, lumps of ice.

(*a*) Carefully dry the calorimeters and weigh each.

(*b*) Fill one calorimeter with water up to a certain volume. Fill the other calorimeter with exactly the same volume of a given liquid.

(*c*) Place the calorimeters in a beaker of water and heat to 50° and then quickly dry them on the outside, place them in the cooling apparatus and insert the thermometers.

(*d*) Note the respective times taken to cool through 10°, say from 50° to 40°.

(*e*) Take the calorimeters out of the apparatus and weigh them to obtain the weights of the liquids used.

Then if s_1 = specific heat of the liquid

t_1 = time taken by liquid to cool through 10°.

t_2 = time taken by water to cool through 10°.

m_1 = mass of liquid.

m_2 = mass of water.

Since total heat lost by each vessel is proportional to the time taken in cooling through 10°,

$$\therefore \quad \frac{\text{heat lost by liquid}}{\text{heat lost by water}} = \frac{m_1 s_1 \times 10}{m_2 \times 10} = \frac{t_1}{t_2}.$$

$$\therefore \quad \frac{m_1 s_1}{m_2} = \frac{t_1}{t_2},$$

or

$$s_1 = \frac{m_2}{m_1} \cdot \frac{t_1}{t_2}.$$

(*f*) Repeat the experiment, using only one calorimeter, and note the time of fall of temperature, (1) with water, (2) with glycerine. Compare the results by these two methods and discuss the advantages of each.

(*g*) Calculate the water equivalent of the calorimeter (C), and calculate the specific heat from the formula

$$\frac{C + m_1 s_1}{C + m_2} = \frac{t_1}{t_2}.$$

e.g. for castor oil :

$$C = 4.16 \times 0.212 = 0.88,$$

$$m_1 = 11.24 \text{ grams},$$

$$m_2 = 11.93 \text{ grams},$$

$$t_1 = 176 \text{ seconds},$$

$$t_2 = 378 \text{ seconds},$$

$$S \text{ (calculated)} = 0.451.$$

37. Determination of the specific heat of a liquid by Andrews's calorifer.

Apparatus.—Consists of a large thermometer (Fig. 40) of the following dimensions. The bulb A is 4.7 cms. in diameter, and is blown on glass tubing of about 5 mms. external diameter and 1 mm. bore.

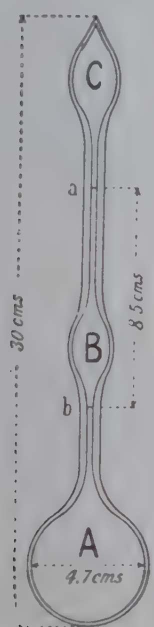

FIG. 40.—Andrews's calorifer.

The two bulbs B and C are about 1 cm. in length and 6 mms. in diameter. The total length of the calorifer is about 30 cms.; on the stem there are two marks a and b which are about 9 cms. apart. The calorifer is suspended in a metal vessel and heated until the mercury stands some distance above the upper mark a, then if the instrument is immersed in a known weight of water the heat given out by the mercury in falling from a to b can be definitely determined. By immersing the calorifer in a known weight of any other liquid the specific heat of the liquid can be calculated.

(i.) **To determine the constant (H) of the instrument,** *i.e.* the amount of heat given up when the mercury falls from the mark a to b.

(a) Suspend the calorifer in the metal heater until the mercury thread is about 1 inch higher than the upper mark a.

(b) Weigh out a quantity of water (m) in a large calorimeter and take the temperature of the cold water (t_0°). Now take the calorifer out of the heater and wait until the mercury thread has just fallen to the mark a, then quickly immerse the instrument in the water, stir well, and wait until the mercury has fallen to the lower mark b, then quickly note the temperature of the water. Add the cooling correction to this and obtain the corrected temperature (t_0').

(c) The constant of the instrument (H) is given by:

$$H = (m + c)(t_0' - t_0),$$

where c is the water equivalent of the calorimeter and stirrer.

(d) Repeat the experiment three times and take the mean of these values as H.

(ii.) **To determine the specific heat of any liquid.**

(*a*) Weigh out about 500 c.cs. of the liquid into the calorimeter and take the temperature (t_1°).

(*b*) Heat the calorifer and immerse it in the liquid when the thread has dropped to the mark *a*. Note the temperature of the liquid when the thread has dropped to the mark *b*. Add the cooling correction and call the corrected temperature t_2°.

Then if s = specific heat of liquid,

$$M = \text{mass of liquid used,}$$
$$H = (Ms + c)(t_2 - t_1).$$
$$\therefore \quad s = \frac{H - c(t_2 - t_1)}{M(t_2 - t_1)},$$

where H is the constant as found above and c is again the water equivalent of the calorimeter and stirrer.

e.g. Weight of calorimeter + water = 444 grams.
Weight of calorimeter alone = 105 grams.
Weight of water (m) = 339 grams.

When heated and placed in this water the calorifer raised the temperature from 14°.3 to 20°.1.

Also

$$C = 105 \times .093$$
$$= 9.76 \text{ grams.}$$
$$\therefore \quad H = 348.76 \times 5.8$$
$$= 2023.$$

In an experiment to find the specific heat of olive oil

$$M = 309 \text{ grams.}$$
$$C = 9.76 \text{ grams.}$$
$$t_1 = 14^\circ.7.$$
$$t_2 = 27^\circ.5.$$
$$\therefore \quad S = \frac{2023 - (9.76 \times 12.8)}{309 \times 12.8}$$
$$= 0.479.$$

The quantity of liquid used should be such that when the calorifer has given up all its heat the thread of mercury should fall below the mark *b*.

Additional Notes on Chapter VI.

(*a*) In the case of the determination of the specific heat of a powder or of a solid which is attacked by water, some other liquid such as aniline or glycerine must be placed in the calorimeter. The heat gained by the liquid will therefore be $W \cdot S(t_2 - t_1)$ units, where S = specific heat of aniline or turpentine.

(*b*) Experiments 31, 32, 34, 35 may be performed in a vacuum flask or an ordinary Thermos flask instead of the usual calorimeter. The water equivalent of the flask is determined by partly filling it with hot water and then pouring in cold water noting the temperatures in the usual manner. The flask may then be used as a calorimeter, but the cold substance (or liquid) must be dropped into the hot water (or liquid) placed in the flask, and the fall of temperature then taken. It will be found that radiation effects are considerably reduced, and large quantities of liquid may be used for calorimetric tests.

Additional Exercises.

1. Find the specific heat of the given specimen of ore.

2. The specific heat of copper being 0.095, find that of the given liquid. (B.Sc. Pass Lond. 1891.)

3. Measure the specific heat of a given liquid by the method of cooling. (B.Sc. Pass Lond. 1891.)

4. Plot the curve of cooling for a couple of liquids and deduce their relative specific heats. (B.Sc. Pass Lond. 1892.)

5. Find the specific heat of paraffin oil. (B.Sc. Pass Lond. 1893.)

6. Find the specific heat of ice, given paraffin oil of specific heat 0.5 and a freezing mixture. (B.Sc. Hons. Lond. 1895.)

7. Compare the specific heat of the given solid with that of the given liquid. (B.Sc. Pass Lond. 1896.)

8. Measure the specific heat of a given solid applying corrections for the material of the calorimeter, etc., and for cooling. (B.Sc. Pass Lond. 1897.)

9. Compare the rate at which water in a copper vessel absorbs heat when placed over a flame—while warming up and after it has begun to boil. (Int. Sci. Hons. Lond. 1899.)

10. Measure the specific heat of a given non-metallic solid. (B.Sc. Pass Lond. 1900.)

11. Determine the specific heat of the given salt by the method of mixtures in a water calorimeter. (Int. B.Sc. Hons. Lond. 1907.)

12. Plot the curve of cooling for the two liquids, and compare their specific heats. (Ext. B.Sc. Pass Lond. 1909.)

13. Find the specific heat of a normal solution of common salt in water. (Ext. B.Sc. Pass Lond. 1909.)

14. Determine the specific heat of a liquid by the method of cooling, taking into account the water equivalent of the calorimeter. (Ext. B.Sc. Pass Lond. 1910.)

15. Determine the specific heat of india-rubber, applying the cooling correction. (Int. B.Sc. Pass Lond. 1911.)

16. Find the ratio of the specific heat of the given solid to that of the given liquid. (Board of Education, 1906.)

17. Find the temperature of the muffle furnace by means of a calorimetric method.

18. Compare the specific heats of aluminium and mercury by the method of mixtures.

19. Determine the specific heat of benzene by immersing in it (*a*) brass, (*b*) mercury.

20. Find the specific heat of a 25 per cent. solution of ammonium chloride.

21. Determine the specific heat of common salt, using (*a*) turpentine, (*b*) benzene.

22. Compare the specific heat of iron between 0° C. and 50° C. with that between 50° C. and 100° C.

23. Compare the specific heat of nitrobenzene obtained (*a*) by method of cooling, (*b*) by immersing a solid of known specific heat in the liquid.

24. Determine the specific heat of ethyl alcohol as follows: Heat a known weight of the substance in a sealed glass bulb and immerse it in aniline. Determine the specific heat of glass previously and make an allowance for the thermal capacity of the bulb. Calculate the result as in the method of mixtures.

25. Determine the specific heat of a solution of sodium chloride of three times normal strength by the method of mixtures. (Ext. B.Sc. Hons. Lond. 1911.)

CHAPTER VII.

LATENT HEAT OF FUSION AND VAPORISATION.

38. Latent heat of fusion.

Apparatus.—Beaker, calorimeter, stirrer, ice, filter paper, centigrade thermometer.

(i.) (*a*) Place in a beaker a mixture of ice and water and note the temperature is 0° C.

(*b*) Place a Bunsen burner under the beaker and stir vigorously with a wire-gauze stirrer. Note that the temperature remains at 0° C. until all the ice is melted, when the temperature gradually rises.

(ii.) (*a*) Weigh out a known quantity of warm water at about 30° C. into a calorimeter and note the exact temperature.

(*b*) Dry some pieces of ice with filter paper and drop lumps into the warm water until the temperature falls to about 10° C. After waiting until the ice is melting note the temperature and weigh the calorimeter and contents to find the weight of ice melted.

(*c*) Calculate the heat lost by the hot water and also the heat required to raise the water formed from the ice to the temperature of the mixture.

It will be found that the heat lost is considerably greater than the heat gained as calculated above.

From the results of Expt. 38, (ii) we may conclude that when a solid like ice is melted a certain amount of heat is taken up in changing its state from solid to liquid. The heat thus absorbed is known as the *latent heat of fusion.*

(iii.) Place some crystals of sodium thiosulphate in a flask, immerse the flask in warm water at a temperature of about 60° C. until the crystals have melted, and plug the mouth of the flask with cotton wool. Allow the flask to cool slowly, remove the cotton plug and introduce a thermometer having on its bulb a crystal of sodium thiosulphate. This causes the liquid to crystallise rapidly, and a sudden rise in temperature is registered on the thermometer, thus showing that there is a sudden evolution of heat when a liquid solidifies.

39. Determination of the latent heat of fusion of ice.

The latent heat of fusion of ice is the quantity of heat required to convert 1 gram of ice at 0° into 1 gram of water at 0°.

Apparatus.—Calorimeter, thermometer, ice.

(*a*) Dry and weigh the calorimeter.

(*b*) Place it in water to the depth of about 2 inches at a temperature of about 30°. Weigh the calorimeter and water to find the weight of the water (w).

(*c*) Dry some small pieces of ice by means of filter paper. Now take the exact temperature of water in the calorimeter (t), drop the pieces of ice into it and stir rapidly until all the ice has melted. Enough ice should be added to cause the temperature of the mixture to fall to 10° C. Take the temperature of the mixture (t_1°).

(*d*) Weigh the calorimeter and contents again and by subtracting the previous weight find the weight of ice used (M).

(*e*) Calculate the results as follows:

Let L = latent heat of ice.

Then heat required to melt the ice = ML.

Heat required to raise the temperature of the water formed from 0° to t_1° = Mt_1.

Heat lost by warm water = $w(t-t_1)$.

Heat lost by calorimeter = $c(t-t_1)$.

(c = weight × 0.093).

$$\therefore\ ML + Mt_1 = (w+c)(t-t_1).$$

$$ML = (w+c)(t-t_1) - Mt_1.$$

$$L = \frac{(w+c)(t-t_1) - Mt_1}{M}.$$

(*f*) Repeat the experiment several times and take the mean of the results.

e.g. Weight of calorimeter = 36.91 grams.

$c = 3.43$ grams. $w = 65.06$ grams.

$t = 25^\circ.1.$ $t_1 = 14^\circ.3.$

$M = 7.92$ grams.

$\therefore$ L (calculated) = 79.1.

40. Determination of the latent heat of fusion of a solid.

Apparatus.—Calorimeter, beaker, thermometer, paraffin wax.

The *heat of solution of a solid* is the amount of heat required to melt 1 gram of the solid at its melting point and convert it into 1 gram of liquid, also at the temperature of the melting point.

(*a*) Weigh the calorimeter empty and place in it about 5 grams of paraffin wax, of known specific heat, and again weigh. This gives the weight of the wax (M).

(*b*) Take some hot water at a temperature of about 70° C., and after reading the temperature of the calorimeter (t°) and that of the hot water (T°) fill the calorimeter two-thirds full of it.

(*c*) Stir the contents of the calorimeter well, taking care that enough hot water has been added to melt all the wax. Take the temperature (t_1°) of the mixture.

(*d*) Now weigh the calorimeter and contents and so find the mass of water (m) that has been poured in.

If L = the heat of fusion of wax, *i.e.* the amount of heat to melt 1 gram of wax.

s = specific heat of wax.

w = water equivalent of calorimeter and thermometer.

Then Heat given up by hot water $= m(T - t_1)$.

Heat taken up on melting the wax = ML.

Heat taken up on raising the temperature of the wax and calorimeter

$$= (Ms + w)(t_1 - t);$$

$$\therefore ML + (Ms + w)(t_1 - t) = m(T - t_1).$$

$$ML = m(T - t_1) - (Ms + w)(t_1 - t).$$

$$L = \frac{m(T - t_1) - (Ms + w)(t_1 - t)}{M}.$$

The specific heat of paraffin wax may be taken as 0.68, and we assume it to be the same in both solid and liquid state. This assumption is not quite correct and would have to be allowed for in an accurate experiment.

The calculation would require modification as follows:

Let t_2 = melting point of solid,
s_1 = specific heat of substance in solid state,
s_2 = ,, ,, ,, liquid state.

Then, as above,

Heat required to raise the temperature of the solid and calorimeter from t° to the melting point $t_2^\circ = (Ms_1 + w)(t_2 - t)$.

Heat required to melt M grams of solid $= ML$.

Heat required to raise the temperature of M grams of liquid formed from t_2° to $t_1^\circ = (Ms_2 + w)(t_2 - t_1)$.

Heat lost by m grams of water $= m(T - t_1)$;

$$\therefore \; ML + (Ms_1 + w)(t_2 - t) + (Ms_2 + w)(t_1 - t_2) = m(T - t_1),$$

from which L may be calculated.

41. Determination of the specific heat of a solid by Black's ice calorimeter.

Apparatus.—A block of clear ice about 6 inches cube with a smooth cylindrical hole about 2 inches diameter and 2 inches

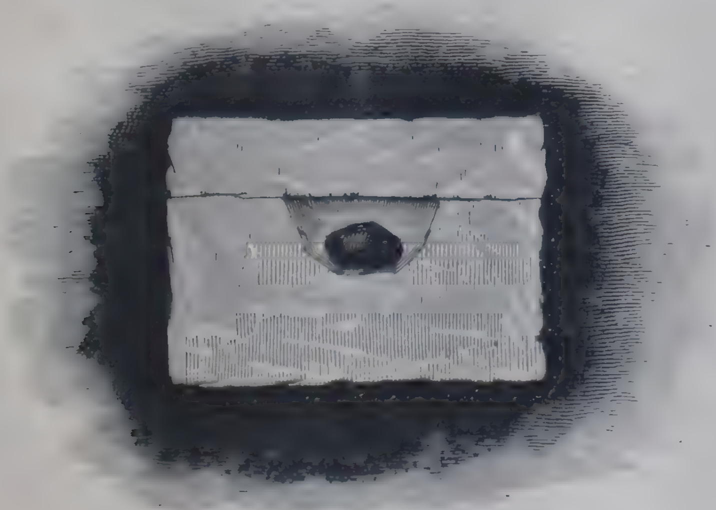

Fig. 41.—Black's ice calorimeter.

depth (Fig. 41) and a slab of ice over the cavity in order to prevent the heat of the room from interfering with the experiment.

(*a*) Weigh the solid (m_1) and heat it in the steam heater which is at a temperature T°.

(*b*) Wipe out the ice cavity by means of a cloth. Then quickly transfer the substance from the heater to the cavity and replace the slab of ice on top.

(*c*) After the end of a few minutes the solid will have parted with all its heat in melting some of the ice, and its temperature will be 0° C. Transfer the water formed to a weighed calorimeter by means of a small pipette, and wipe out the cavity by a piece of weighed filter paper.

(*d*) Calculate the weight of ice melted (m_2).

Then if L = latent heat of fusion of ice (from previous experiments).

s = specific heat of the solid.

$$m_2 L = m_1 s . T.$$

$$\therefore\ s = \frac{m_2 L}{m_1 T}.$$

42. Latent heat of vaporisation.

Apparatus.—Flask, beaker, thermometer.

(*a*) Boil some water in a flask, and notice that the boiling point is approximately 100° C. and remains constant while the water is passing into steam. Heat is required to convert the water into steam at the same temperature.

(*b*) Fit the flask with a cork and delivery tube, the end of which dips into cold water. It will be noticed that the steam condenses in the water and the heat which was previously rendered latent has been recovered.

43. Determination of the latent heat of steam.

The *latent heat of steam* at any temperature is the quantity of heat required to convert one gram of water at that temperature into steam at the same temperature.

Apparatus.—A copper condenser A fitted with two openings, one of which, B, can be connected to a supply of steam from a flask (Fig. 42). The condenser is immersed in a calorimeter

containing cold water, and is packed round with cotton wool or placed in an enclosure to prevent radiation. The steam delivery tube should slope down towards the flask so that any condensed water may run back. A steam trap C is also added.*

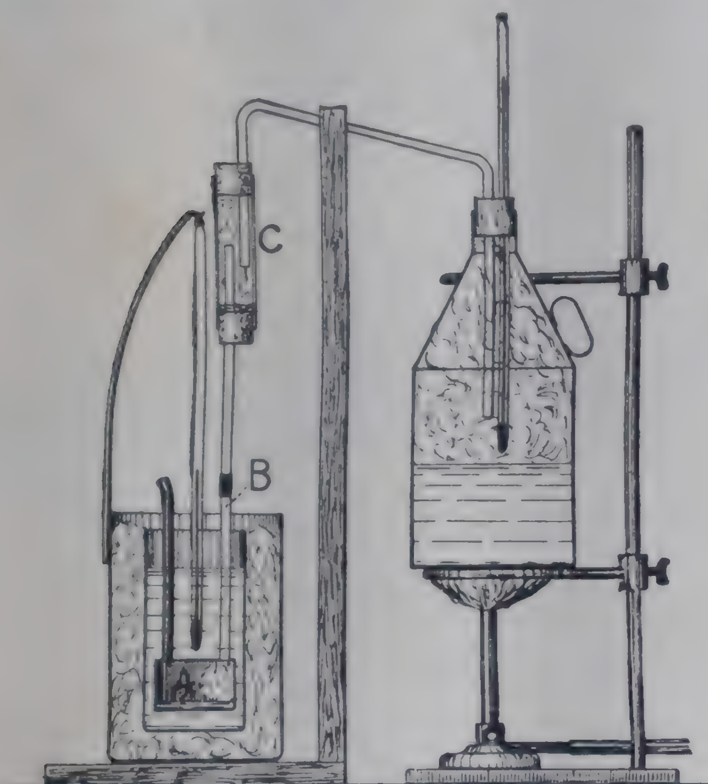

FIG. 42.—Apparatus for the determination of the latent heat of steam.

(*a*) While the water in the flask is boiling weigh the empty calorimeter and also the empty condenser.

(*b*) Fill the calorimeter with water slightly above the level of the condenser, and find the weight of water introduced (w).

(*c*) When steam has been passing through the glass tube for some minutes attach the delivery tube to the condenser, and at the same time note the temperature of the water in the calorimeter (t).

* The outlet tube of the trap should be bent over at the top so as to prevent splashes of condensed water dropping down. In Berthelot's apparatus the vapour is passed direct from the boiler to the condenser vertically below it, thus reducing the evaporation from the partial condensation in the condenser tube.

(*d*) When the temperature of the calorimeter has risen to about 35° C., disconnect the delivery tube and note the highest temperature ($t_1°$) of the calorimeter.

(*e*) When, after stirring well, the temperature begins to fall, allow the calorimeter to cool for *half* the time during which steam was passing into the condenser and note the fall in temperature. This will give the fall in temperature due to cooling during the experiment. Add this fall in temperature to the above temperature ($t_1°$) and thus get the corrected temperature of the calorimeter ($t_2°$). This is a fairly accurate method of allowing for the cooling correction, but, of course, not so accurate as the one obtained from the cooling curve. (Expt. 32.)

(*f*) Dry the outside of the condenser and weigh the contents after the experiment to obtain the weight of steam condensed (M). This weighing must be done quickly in order to prevent loss by evaporation.

Then if L = latent heat of steam,

T° = temperature of steam used,

(This is read on the thermometer in the flask.)

C = water equivalent of calorimeter and condenser, *i.e.* weight × 0.093.

$$\text{Heat gained by water} = w(t_2 - t).$$

$$\text{Heat gained by calorimeter} = C(t_2 - t).$$

Heat given up in converting M grams of steam into water at T° = ML.

Heat given up in dropping M grams of water from T° to $t_2° = M(T - t_2)$.

$$\therefore\ ML + M(T - t_2) = (w + C)(t_2 - t),$$

$$ML = (w + C)(t_2 - t) - M(T - t_2).$$

$$\therefore\ L = \frac{(w + C)(t_2 - t) - M(T - t_2)}{M}.$$

(*g*) Repeat the experiment and take the mean of the results.

e.g. Weight of condenser	= 47·35 grams.
" calorimeter	= 47·34 "
" calorimeter + condenser + water	= 256.20 "
∴ weight of water (w)	= 161.51 "
Initial temperature (t)	= 13°.8.

Steam passed in for one minute.

Temperature after stirring	$=43^{\circ}.2$.
Cooling during $\frac{1}{2}$ minute	$=0^{\circ}.2$.
Corrected final temperature (t_2)	$=43^{\circ}.4$.
Temperature of steam (T)	$=99^{\circ}.8$.
Weight of condenser after experiment	$=55.92$ grams.
∴ weight of condensed steam (M)	$=8.57$ grams.
Water equivalent of calorimeter and condenser (C)	$=8.81$ grams.
∴ latent heat of steam (L)	$=\underline{532.1}$.

44. Determination of the amount of moisture in a given weight of steam.*

It will be noticed in the last experiment that a certain amount of moisture is carried over by the steam and this moisture is collected in the water-trap.

It is rather important to steam users to know the 'dryness fraction,' *i.e.* the ratio of the weight of dry steam to that of the total amount of steam supplied.

Apparatus.—Large calorimeter of about 500 c.cs. capacity, boiler, delivery tube without water-trap attachment.

(*a*) Weigh out about 300 grams of cold water into the calorimeter. Note the weight of water (w) and the temperature ($t_1{}^{\circ}$).

(*b*) After getting up steam in the boiler, place the delivery tube in the calorimeter and pass in steam until the temperature is about 50° C. Note the cooling correction as in the previous experiment and thus obtain the temperature of the mixture (t_2).

(*c*) Weigh the calorimeter and contents and thus find m the weight of steam used. Note the boiling point of water (T) and from tables find the latent heat of steam (L) at this temperature.

* Engineering students are referred to text-books on Heat Engines for the use of the "Throttling" calorimeter and the "Separating" calorimeter. The former mechanically separates the moisture from the steam, while in the latter the steam is allowed to pass through a small orifice and to become superheated.

Then if x = weight of dry steam supplied,

$$xL + m(T - t_2) = (w + C)(t_2 - t_1);$$

$$\therefore \quad x = \frac{(w + C)(t_2 - t_1) - m(T - t_2)}{L},$$

where C = water equivalent of the calorimeter.

$$\text{Dryness fraction} = \frac{x}{m} \times 100 \text{ per cent.}$$

e.g.

Weight of calorimeter	= 102.5 grams.
Weight of calorimeter + water	= 414.0 grams.
Weight of water (w)	= 311.5 grams.
t_1	= 13°.9.
t_2 (corrected)	= 42°.3.
T	= 100°.
L	= 536.
m	= 16.3 grams.
∴ x (calculated)	= 15.3 grams.
Dryness fraction	= 93.8 per cent.

45. Total heat of steam.

The total heat of steam at any temperature $t°$ C. is the amount of heat required to convert 1 gram of water initially at 0° C. into steam at a temperature of $t°$ C. In order to vary the boiling point of the liquid it is evident that the pressure must be varied in some suitable manner.

Regnault found that for a temperature $t°$ C.,

$$L_t = 606.5 - 0.695t$$

and

$$H_t = 606.5 + 0.305t,$$

where L_t and H_t are the latent heat and total heat of steam respectively for the temperature $t°$ C.

46. Determination of the latent heat of alcohol vapour.

Apparatus.—Similar to that used in the determination of latent heat of steam except that a flask is filled with alcohol and is heated by means of a water bath. Alcohol is also placed in the calorimeter.

The experiment is conducted in the same way as the determination of the latent heat of steam.

If L = latent heat of alcohol,
T° = temperature of alcohol vapour.
c = water equivalent of calorimeter and condenser.
$t°$ = initial temperature of calorimeter.
s = specific heat of alcohol (from Tables, p. 196).
$t_2°$ = final temperature of calorimeter, after adding cooling correction.
M = mass of alcohol vapour condensed.
w = weight of alcohol in calorimeter.

$$ML + Ms(T - t_2) = (ws + c)(t_2 - t).$$

$$\therefore \quad L = \frac{(ws + c)(t_2 - t) - Ms(T - t_2)}{M}.$$

Additional Exercises.

1. Use Black's ice calorimeter to determine the specific heat of brass.

2. Determine the latent heat of liquefaction of benzoic acid. (B.Sc. Hons. Lond. 1891.)

3. Determine the latent heat of methylated spirits assuming the specific heat of the spirits is 0.635.

4. Measure the latent heat of ice by the method of mixtures. (B.Sc. Pass. Lond. 1897.)

5. Determine the latent heat of liquefaction for Wood's metal.

Melting point = 75°.5 C.
Specific heat (solid) = 0.0352.
" " (liquid) = 0.0426.

6. Find the latent heat of vaporisation of benzene. (Boiling point = 80°.1 C.)

7. Determine the latent heat of evaporation of the given liquid. (Int. B.Sc. Pass Lond. 1906.)

8. Determine the specific heat of the given crystal by means of Joly's steam calorimeter. (Int. B.Sc. Hons. Lond. 1906.)

9. Find the latent heat of fusion of the given solid. (Ext. B.Sc. Pass Lond. 1908.)

10. Find the latent heat of evaporation of alcohol. (Ext. B.Sc. Pass Lond. 1908.)

CHAPTER VIII.

CHANGE OF STATE.

47. Fusion.

When a solid passes into a liquid state by means of the application of heat, the temperature remains constant during the process of fusion or melting. A similar result occurs during the reverse process of solidification. Hence by plotting what is known as a *cooling curve* with simultaneous observations of the time and temperature we can deduce from this curve the melting point of the solid.

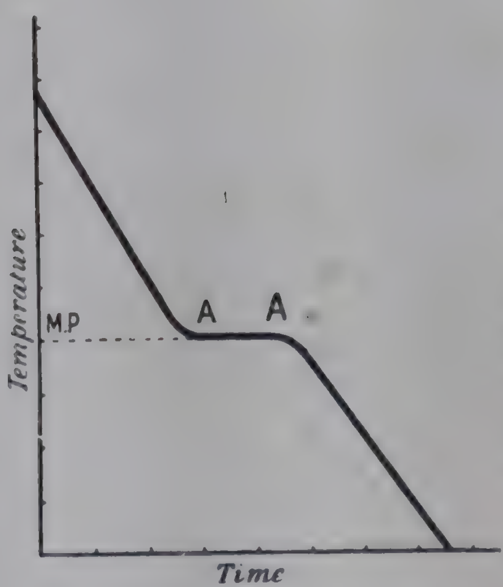

FIG. 43.—Cooling curve for paraffin.

Apparatus.—Paraffin wax, test tube, thermometer.

(*a*) Place some paraffin wax in a test tube and after melting it insert a thermometer. Allow the wax to cool in the air and note the temperature at intervals of one minute.

(*b*) Plot the cooling curve which will be similar to that in Fig. 43. The melting point (M.P.) is obtained by drawing a line on to the axis of temperatures from the portion of the curve AA representing the period of solidification.

48. Determination of the melting point of paraffin wax.

Apparatus.—Small lengths of capillary tubes, beaker, thermometer, stirrer, paraffin wax, crucible.

(*a*) Stick the end of one of the capillary tubes into the wax until it is filled to one half the distance from the bottom end.

(*b*) Fasten the tube to the thermometer with an indiarubber band and support it vertically in a beaker of water placed on a tripod stand.*

(*c*) Heat the water, keeping it constantly stirred. Note the temperature at which the wax begins to be transparent.

(*d*) Take away the burner and allow the water to cool. Note the temperature at which the wax begins to solidify.

(*e*) Lower the flame and heat very gently so as to repeat the above experiment more accurately.

(*f*) Repeat this three times and enter up the results in some convenient form. Take the mean of the results as the melting point of the wax.

49. Determination of the melting point of an alloy.

As stated previously, if a solid is melted and then allowed to cool, the temperature being taken at equal intervals of time and a curve plotted with times as abscissae and temperatures as ordinates, then it will be noticed that part of the curve is horizontal (Fig. 43). This part represents the period at which the solid is giving up its latent heat and is partly solid and partly liquid, and it determines for us the solidification point of the solid, which is the same as its melting point.

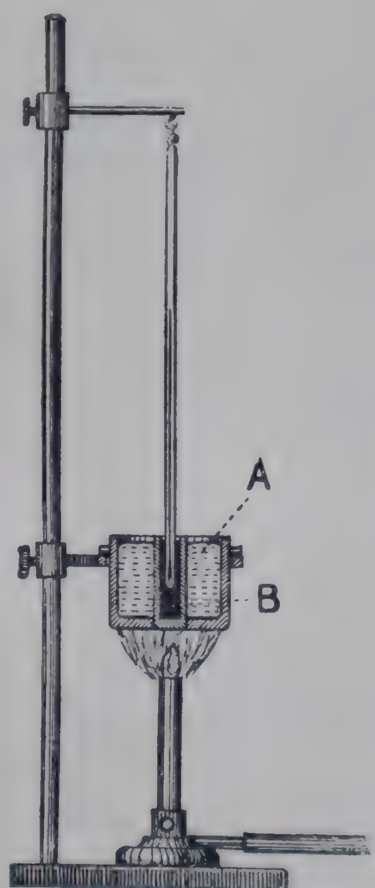

FIG. 44.—Apparatus for determination of the melting point of a metal or alloy.

* The experiment may be conducted in a large test-tube containing concentrated sulphuric acid. In the case of fine powders it will be found preferable to scoop them from a watch glass into the open end of a capillary tube, tapping the tube until it is packed to a depth of about 5 mms. The success of the experiment depends on the use of a small source of heat and on a gradual rise in temperature.

If the solid is an alloy of two metals there will be two horizontal portions of the curve (Fig. 45). The object of the following experiment is to determine the melting points of the constituents of an alloy by noting at what temperatures the readings are almost constant.

Apparatus.—Metal outer vessel A containing the alloy (Fig. 44). An inner metal tube B contains mercury* in which a thermometer is inserted, to determine the temperature.

A strong form of apparatus can be made by taking a blank end of some $2\frac{1}{2}$ inch steam tubing and drilling the end so as to screw in a piece of solid $\frac{1}{2}$ inch steel rod. The hole drilled out is of a smaller size than the rod and is expanded by heating the tubing to redness, so that the rod can be fitted in and grips tightly when at a lower temperature. The steel rod is cut off flushed with the top and drilled out so as to form a receptacle for the thermometer. By surrounding the thermometer with fine aluminium or copper filings and by using a hard Jena glass thermometer, melting points can be determined up to 500° C.

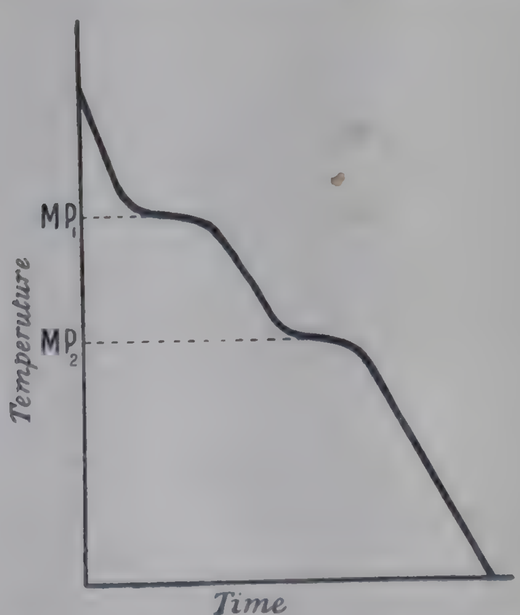

FIG. 45.—Curve for the melting point of an alloy.

(i.) (*a*) Place some metallic tin in the outer vessel.

(*b*) Heat it to about 260° C. when it will melt.

(*c*) Now take away the burner so that the vessel will cool at an even rate.

(*d*) Take readings on the thermometer every minute and plot a curve with the results as shown in Expt. 48. Note the temperature of the horizontal part of the curve which determines the melting point.

(ii.) (*a*) Place in the vessel an alloy of tin and lead (*e.g.* 7 parts lead and 1 part tin), heat it to about 320° C. and then allow it to cool.

*Melted paraffin or cylinder lubrication oil may be used with advantage.

(*b*) Read the temperature at intervals of one minute, until the alloy is solidified, and calculate the drop in temperature each minute. There will be two points at which the drop in temperature is very small, and these points are the melting points of the constituents of the alloy.

(*c*) Plot a curve with the results and determine the two melting points from the curve (Fig. 45), *e.g.*

Time, . .	0′	1′	2′	3′	4′	5′	6′	7′	8′	9′	10′
Temp. °C.	314°	300°	290°	282°	275°	269°	261°	252°.2	242°	231°.5	221°
Difference,	14°	10°	8°	7°	6°	8°	8°.8	10°.2	10°.5	10°.5	

Time, ...	11′	12′	13′	14′	15′	16′	17′
Temp. °C., . . .	210°	200°	190°	181°.5	177°.9	171°.5	163°.0
Difference, ...	10°	10°	8°.5	3°.6	6°.4	8°.5	

$$MP_1=275°\text{ C.} \qquad MP_2=179°\text{ C.}$$

50. Determination of the coefficient of depression of the freezing point of a solution.

When a salt is dissolved in a certain solvent, *e.g.* water, the freezing point of the solvent is lowered, and the larger the amount of salt dissolved the greater is the depression of the freezing point.

If k = coefficient of depression of the freezing point, *i.e.* the depression produced by dissolving 1 gram of the substance in 100 grams of the solvent,

m = mass of salt dissolved.

M = mass of solvent.

d = depression observed.

$$k=\frac{\mathrm{M}d}{100m}.$$

Apparatus.—A Beckmann's apparatus (Fig. 46) which consists of a tube A into which the liquid is placed and which has a side tube D through which the solid is introduced. The tube A is surrounded by an air jacket by means of a second tube B,* while

* For accurate work this outer tube B may be replaced by a Dewar vacuum vessel.

the outer vessel C contains the freezing mixture and a stirrer. The sensitive thermometer T reading to 0°.01 C. registers the depression.

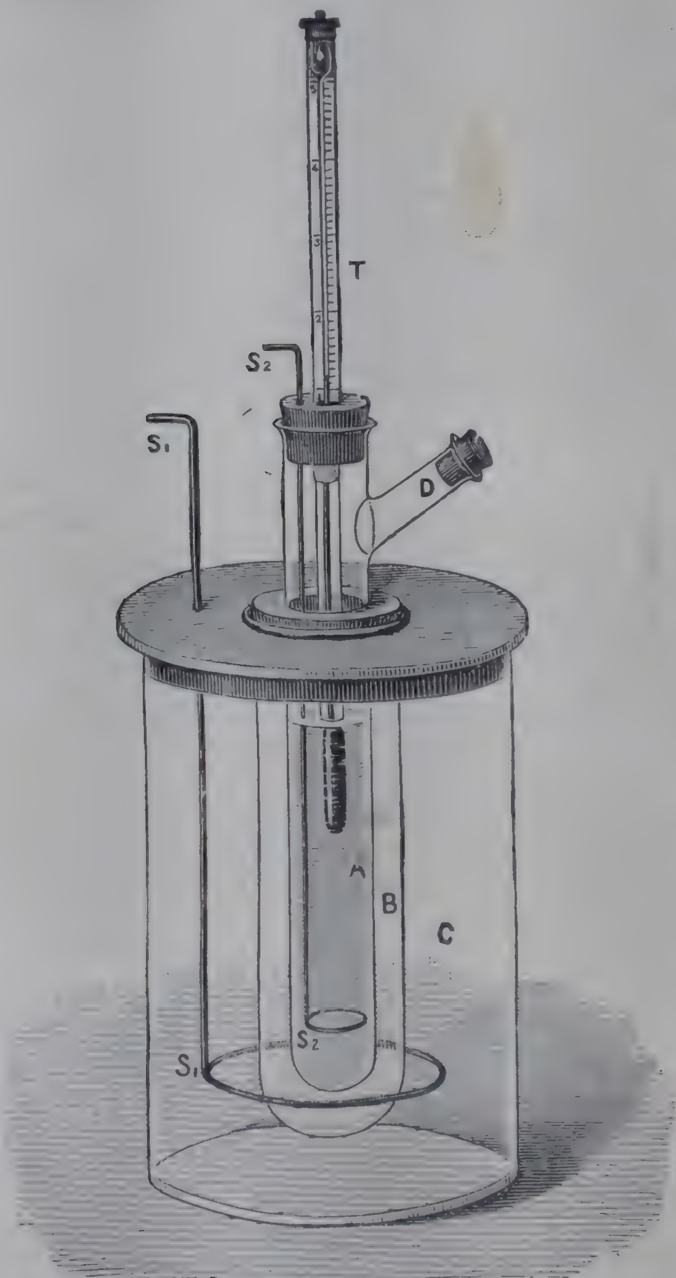

FIG. 46.—Beckmann's apparatus for the determination of the freezing point of a solution.

(i.)(*a*) Run a known weight of the given liquid into A through the tube D. Place a suitable freezing mixture inside C and keep the contents of A well stirred by means of the small platinum stirrer S_2. The mercury thread will gradually fall to a certain point and then slightly rise and become steady until all the liquid is solidified. Note the freezing point.

Note.—Before conducting the experiment the thread of mercury in the thermometer must be adjusted so that the freezing point of the solution is nearly at the top of the scale, thus allowing the depression to be observed on the scale.

(*b*) Take out the tube A and allow the contents to melt. Now weigh out accurately about 0.5 gram of the solid and drop it into A and again note the freezing point. The difference between the two freezing points gives the depression (d_1).

Weigh out a further 0.5 gram of the substance and again note the depression produced on adding it to the previous solution. Call this depression (d_2) counting from the previous freezing point.

If m_1 = weight of salt in 1st case.

m_2 = weight of salt in 2nd case.

Then $k = \dfrac{Md_1}{100m_1}$ in 1st case.

$k = \dfrac{M(d_1 + d_2)}{100(m_1 + m_2)}$ in 2nd case.

Take the mean value of k as the coefficient of depression.*

If a is the depression produced by dissolving the molecular weight W of the substance in 100 grams of the solvent,

$$a = W \cdot k, \quad \text{or} \quad W = \frac{a}{k}.$$

(ii.) (*a*) Assuming the values of a for water and benzene from the Tables, p. 200, calculate the molecular weight of sodium chloride and benzoic acid. The benzoic acid should be purified by recrystallization.

e.g. for NH_4Cl dissolved in water

$$m_1 = 0.5 \text{ gram}, \quad d_1 = 0^\circ.265,$$
$$m_2 = 0.5 \text{ gram}, \quad d_2 = 0^\circ.258,$$
$$m_3 = 0.5 \text{ gram}, \quad d_3 = 0^\circ.248,$$
$$M = 120.1 \text{ grams};$$
$$\therefore \quad k(1) = 0.652$$
$$(2) = 0.644$$
$$(3) = \underline{0.634}$$
$$\text{Mean} = 0.643$$

$$\therefore \text{ molecular weight (W)} = \frac{34.5}{0.643} = 53.7.$$

51. Change of volume on solidification and melting.

In Expt. 22 when determining the maximum density of water it may have been noticed that the water in the capillary tube rose slightly from 4° to 0° C. and then a sudden expansion took place when the water commenced to freeze. This

* The value of k may also be calculated from the formula $k = \dfrac{0.02T^2}{L}$, where T is the freezing point of the solvent in absolute measure and L is the latent heat of fusion.

change of volume which, in the case of water, is the cause of the bursting of water pipes during frosty weather, occurs with most solids. The reverse process also occurs, viz. : a diminution of volume will take place when the solid passes into the liquid state. The latter fact is taken advantage of in Bunsen's *ice calorimeter* (Fig. 47).

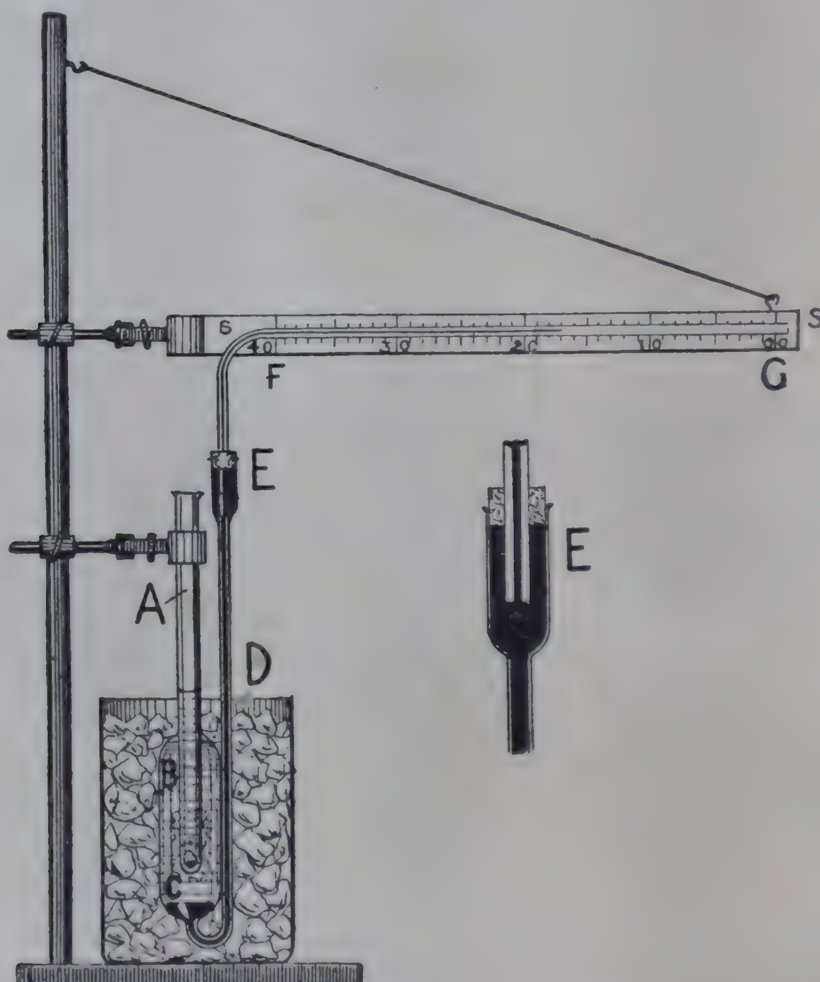

FIG. 47.—Bunsen's ice calorimeter.

Apparatus.—A Bunsen's ice calorimeter.

(*a*) Examine the ice calorimeter. Notice the glass tube A is fused with a larger tube BC, the lower end of which is connected to a bent tube DE. (In the form of apparatus in which the tube DE is touching BC, it is advisable to pass a rubber band round them to prevent breakage.) At the upper end E the tube widens, and into this wide portion is fitted a small rubber stopper through which a piece of bent glass tubing

FG is fixed. A metre scale SS is placed behind FG in order to measure the contraction in the horizontal portion.

(i.) **Method of filling the apparatus.**—Detaching the tube FG take hold of the apparatus and gently warm the tube BC in the flame and dip the open end E under the surface of some clean distilled water. Part of the water will be drawn in and the process is repeated until, after some patience has been expended, the apparatus is filled up to the point E.

After allowing the apparatus to cool, a quantity of clean dry mercury is poured down the tube DE and this mercury displaces some of the water inside and also fills up DE itself. The stopper is now inserted at E and by pushing it in some distance the mercury is forced along the horizontal tube. The apparatus is fixed in a retort stand as in Fig. 47.

To obtain a quantity of ice inside BC the apparatus is surrounded by a freezing mixture of ice and salt until the temperature inside is just above freezing point; it is then transferred to a vessel containing melted ice, and ether is evaporated inside the tube A by blowing air into it. The cold thus produced results in the formation of a quantity of ice round the inner tube, and any ether remaining is wiped out with cotton wool.

Owing to the expansion of the water in freezing, the mercury will probably be forced out of the open end of FG, and it is convenient to have the thread about an inch from the end.

(ii.) **Determination of the constant (K) of the apparatus.**—Heat some water in a beaker to a temperature of about 25° C. and quickly transfer it to a burette. Take the exact temperature of the water, and then run out about 10 c.cs. into the tube A, insert a pad of cotton wool over the top and stir with a fine wire. Note the contraction of the mercury thread along the scale SS after the reading becomes steady, *e.g.* 12 c.cs. of water at 22°.5 C. produced a contraction of 8.3 cms. Since 1 c.c. of water at this temperature weighs 0.997 gram.

$\therefore$ $12 \times 0.997 \times 22.5 = 269.2$ calories produce a contraction of 8.3 cms., or 1 cm. contraction corresponds to 32.4 calories which is the required constant (K).

(iii.) **Determination of the specific heat of a substance.**—Weigh out m grams of the substance of specific heat s and after

heating to a temperature T in a steam heater quickly transfer it to the water inside A, this water being at 0°. Note the contraction l on the scale SS.

Then $$ms\mathrm{T}=\mathrm{K}\,.\,l, \quad \therefore\ s=\frac{\mathrm{K}\,.\,l}{m\,.\,\mathrm{T}},$$

which gives the required specific heat.

52. Effect of pressure on the melting-point.

Apparatus.—Ice, metal wires, drawing board.

(*a*) Take two pieces of ice with fairly plane surfaces and press them tightly together. On releasing the pressure the two blocks of ice will be found frozen together.

(*b*) Take a block of ice and place it on a drawing board supported between two stools. Pass a thin copper or steel wire over the ice and fasten heavy weights to either end. The wire will cut through the ice without dividing it into two parts.

These two experiments show that ice can be made to melt by the application of pressure alone, but that when the pressure is released the water thus formed immediately freezes, showing that its temperature must have been below 0° C. This process is called *regelation.*

53. Evaporation.

Apparatus.—Evaporating dish, thermometer, ether, blowpipe.

(*a*) Weigh a flat porcelain dish containing some water. Allow the water to stand in a cupboard of the laboratory and at the end of a few days weigh again. The weight is less than before, showing some of the water has disappeared.

(*b*) Place a few drops of water on the bulb of a thermometer and move the latter to and fro. Note the temperature before and after the water has disappeared.

(*c*) Repeat Expt. 53 (*b*) with ether on the bulb and note that the temperature falls lower than before.

(*d*) Place some ether in a beaker under which there is a few drops of water. Blow air through the ether with a blowpipe and notice that the water underneath is frozen after a few minutes.

From Expts. 53 (*b*), (*c*) and (*d*) it is evident that heat is required to produce the change of state when liquids evaporate.

54. Boiling.

Apparatus.—Flask, common salt, centigrade thermometer.

(*a*) Heat some water in a clean glass flask and notice the various phenomena that take place. Place a thermometer in the liquid and note that the temperature is practically constant so long as boiling takes place.

(*b*) Place some common salt in the water, and when it has dissolved note the temperature of the solution itself and also the temperature of the vapour.

The former will be higher than 100°, but the temperature of the vapour will apparently be 100° as registered on the thermometer. This is owing to the fact that it is mostly condensed steam on the bulb.

55. Determination of the boiling point of a liquid.

The boiling point of a liquid is the temperature at which the vapour of the liquid exerts a pressure equal to that of the atmosphere. From this definition it is evident that the boiling point of any liquid depends on the pressure of the atmosphere. The normal boiling point for water is 100° C. when the atmospheric pressure is 760 mms.*

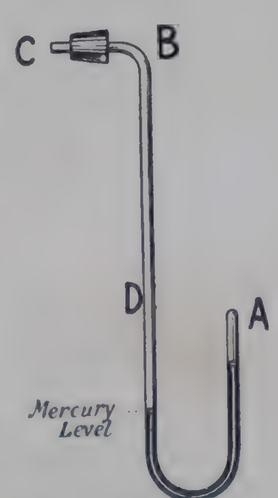

FIG. 48.—Apparatus for the determination of the boiling point of a small quantity of liquid.

The usual method of finding the boiling point is to boil the liquid in a distillation flask fitted with a thermometer and connected to a condenser. When the mercury reading is constant the boiling point is noted. In the following exercise a method is employed which would be useful supposing only a small quantity of the liquid were available.

Apparatus.—Glass tube of about $\frac{3}{16}$ inch bore and shaped as seen in Fig. 48. The end A is closed and the tube is filled

* The boiling point t_p of a liquid at any pressure p is connected with the normal boiling point t_{760} by the equation $t_p = t_{760} + k(p - 760)$, where k is a constant for the given liquid.

with mercury up to the mark B. The horizontal portion BC is filled with liquid and by inverting the tube, keeping the end closed, the liquid will ascend to the end A.

The mercury in BD is now jerked out until its level is lower than that in A. The tube is now ready for the experiment.

(*a*) Fix the tube and contents into a large beaker and arrange a thermometer to take the temperature of the water.

(*b*) Keep the water well stirred and gradually raise its temperature until the level of the mercury in A is just equal to the level in D. When this occurs the pressure of the vapour in the liquid is just equal to the pressure of the atmosphere.

(*c*) Note the boiling point, *i.e.* the temperature of the water, and allow the liquid to cool until the level of mercury is the same as before.

(*a*) Again raise the temperature and repeat the observation taking the mean of these results for the boiling point.

For temperatures greater than 100° C. use conc. sulphuric acid instead of water in the beaker.

56. Variation of the boiling point of a saline solution with the degree of concentration.

Apparatus.—Distillation flask fitted with thermometer reading from 100° to 130° C. graduated in 0°.1, salt, tripod and wire gauze, common salt.

(*a*) Dry and weigh the empty flask together with the stopper and thermometer. Fill the flask half full of water. Insert the thermometer so that the bulb dips well into the liquid. Boil the water and note the boiling point on the thermometer.

(*b*) Weigh out 5 grams of common salt on a filter paper, and carefully transfer the salt to the flask. Boil the solution of salt for about 1 minute and make a note of the boiling point.

(*c*) Weigh the flask and contents, together with the thermometer and stopper, and thus find the weight of the solution.

(*d*) Weigh out another 5 grams of salt and transfer it to the flask. Note the boiling point again, and obtain the mass of the solution.

(*e*) Repeat the above, adding 5 grams of salt at a time until the solution is saturated.

(*f*) Enter results thus :

Weight of empty flask, stopper and thermometer = 103 grams.

Boiling point of water = 100°.2 C.

Weight of salt added.	Weight of flask after boiling.	Weight of solution.	Percentage of salt in solution.	Boiling point.
5.0 grams.	326 grams.	223 grams.	2.24	100°.5
10.0	329	226	4.43	100°.9
15.0	331	228	6.58	101°.3
20.0	332	229	8.73	101°.9
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......

(*g*) Plot a curve having the percentages of solid in solution as abscissae and the corresponding boiling points as ordinates.

(*h*) Repeat the experiment with potassium chlorate and ammonium chloride respectively.

57. Determination of the molecular weight of a substance by the rise in the boiling point of the solvent.

If a solid is dissolved in a liquid the boiling point of the liquid is raised and from the rise in the boiling point the molecular weight of the solid can be determined.

If w grams of solid are dissolved in 100 grams of the solvent whose boiling point is $t_0°$, then the molecular weight (W) of the solid is given by

$$W = \frac{wa}{t - t_0},$$

where a is the molecular rise of boiling point and $t°$ is the boiling point of the solution.

If m grams of the solid are dissolved in M grams of the solvent, then

$$w = 100\frac{m}{M},$$

and

$$W = \frac{100ma}{M(t - t_0)}.$$

Apparatus.—Beckmann's apparatus (Fig. 49) consisting of a boiling flask A fitted with a Beckmann thermometer B * and a condenser C. The opening D serves to introduce the salt. The flask is surrounded by a lamp chimney L and this is closed in by a plate of glass G. The flask is heated on wire gauze covered with a sheet of asbestos.

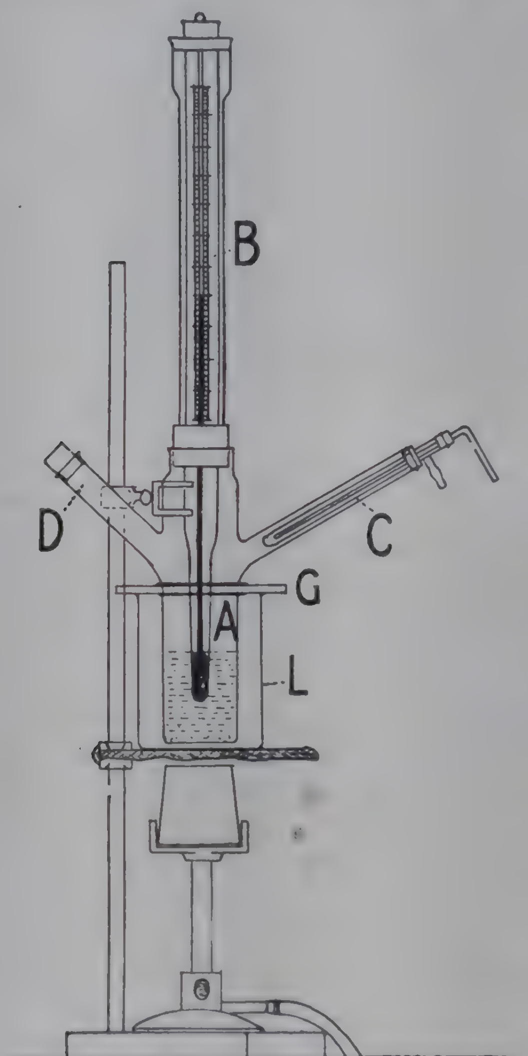

FIG. 49.—Beckmann's apparatus for the determination of the boiling point of a solution.

(*a*) Weigh the boiling flask A. Introduce the solvent and weigh again. The difference gives M the mass of the solvent.

(*b*) Having arranged the thermometer to measure the temperature, gradually heat the solvent until it boils steadily. Note the boiling point ($t_0°$). In order to keep the boiling point constant small pieces of platinum or glass may be introduced into the flask.

(*c*) Weigh out 0.3 to 0.5 gram of the substance (enough to produce a rise in boiling point of 0°.1) and introduce it through the opening D. Determine the boiling point ($t_1°$) of the solution. Call the weight of solid used m_1.

(*d*) Introduce a further weight m_2 of the solid and determine the boiling point ($t_2°$) of the solution.

* A Beckmann thermometer should not be used for several hours after it has been "set." In this experiment, if the substance is a solid, it is best to introduce it into the apparatus in the form of compressed tablets ; in the case of liquids a bent pipette with a narrow orifice is filled and pushed down the side tube D, the liquid being introduced by blowing gently into the pipette.

(*e*) Repeat this four times with fresh amounts of salt.

Then in the first case:

$$w_1 = 100\frac{m_1}{M},$$

$$\therefore \ W = \frac{100 m_1 a}{M(t_1 - t_0)}.$$

In case 2:

$$w_2 = \frac{100(m_1 + m_2)}{M},$$

$$\therefore \ W = \frac{100(m_1 + m_2)a}{M(t_2 - t_0)},$$

and so on for the other cases.

The values of a for various liquids are given in the Tables, p. 200, although these same values may be calculated by the formula

$$a = \frac{0.02T^2}{L},$$

where T = boiling point on the absolute scale.
L = latent heat of vaporisation.

In the case of water

$$a = \frac{0.02(373)^2}{536} = 5.2.$$

Note.—The above apparatus is suitable for temperatures below 130° C. It is not so accurate as the freezing point apparatus because of the variation of the boiling point, due to the drippings of cold liquid from the condensers, and to radiation effects.

58. Determination of the boiling point of water under low pressure.

Apparatus.—As shown in Fig. 50. It consists of:

(A) Bunsen filter pump for reducing the pressure.

(B) Bottle to prevent water from pump flowing back when pump is stopped.

(C) Mercury manometer with metre scale for registering the pressure.

(D) Three-way cock. When the black spot on the handle is to the right, the handle being horizontal, the manometer is in connection with the apparatus. When the handle is vertical with the black spot above, then the manometer and apparatus are in connection with the outer air.

(E) Winchester quart bottle used for keeping the pressure constant and for providing a larger volume of air in the apparatus.

(F) Condenser through which a stream of water flows by syphoning it from the cylinder under the pump.

(G) Flask containing water.

(H) Receiver for condensed water.

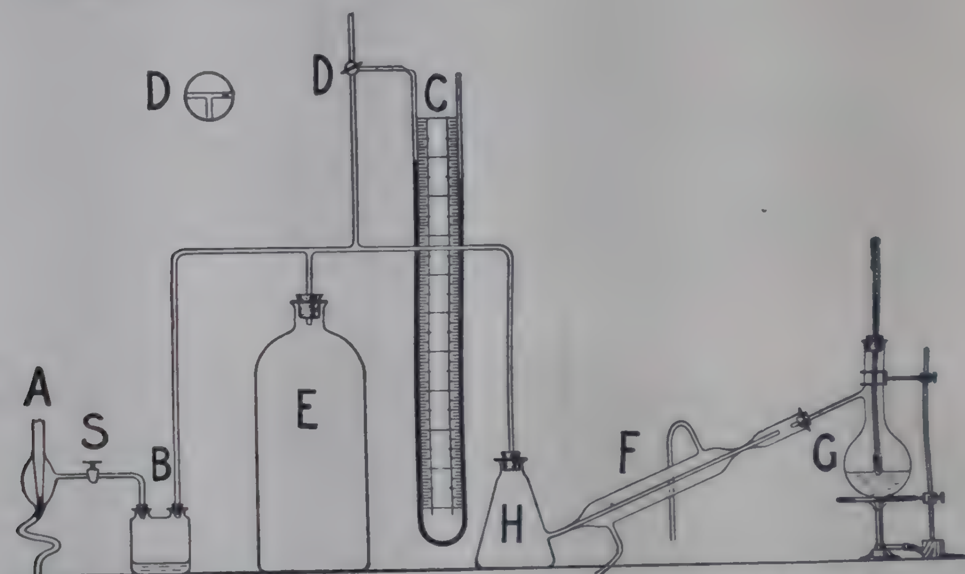

FIG. 50.—Apparatus to determine the variation of the boiling point of water at low pressures.

(*a*) Test the pump and apparatus by starting the flow of water and then opening the stopcock at S, the stopcock at D being closed. The manometer should register the pressure down to 20 mms. of mercury. After testing the apparatus open D and stop the pump after closing S.

(*b*) Set the water boiling in the flask, and keep D open so that the pressure in the apparatus is that of the atmosphere. Note the boiling point on the thermometer and read the height of the barometer.

(*c*) Still keeping the water boiling, close D, and set the pump going.* Then open S and let the pressure be reduced by about 5 cms. Close S, and after waiting a quarter minute for the pressure to become constant, quickly read the manometer and the thermometer.

* To prevent the "bumping" of the liquid during boiling, it may be found useful to introduce into the flask pieces of porous pot or capillary glass tubes.

(*d*) Repeat these observations at intervals of 5 cm. pressure until the minimum pressure is reached.

(*e*) Take observations in the reverse order, *i.e.* with the pressure increasing by opening the stopcock D for a short interval. The flow of water must be stopped and the stopcock S closed during this set of observations. Enter results thus :

PRESSURE DECREASING.

Height of barometer = 75.7 *cms.*

Manometer.		Difference in level.	Total pressure.	Observed boiling point.
a.	*b.*			
cms.	cms.	cms.	cms.	
27.1	27.1	0.0	75.7	99°.9 C.
29.5	24.6	4.9	70.8	98°.1
32.1	22.0	10.1	65.6	96°.0
......	......	......	......	......
......	......	......	......	......

The total pressure is obtained by subtracting the difference in level of the manometer from the height of the barometer.

(*f*) On the same sheet of squared paper plot two curves showing the relation between the total pressures (increasing and decreasing) and the corresponding boiling points.

59. Determination of the pressure of water vapour at temperatures above 100° C. (Papin's digester).

Apparatus.—As in Fig. 51. It consists of a copper boiler A provided with a safety valve B and a Bourdon pressure gauge C, graduated up to 40 lbs. at intervals of quarter pounds. The metal plug in front of the thermometer is unscrewed to fill the boiler with water, while the temperature is measured by a thermometer reading to 150° C. This thermometer is placed in a hollow metal cone let in to the top of the boiler, the cone being partially filled with mercury or melted paraffin.

(*a*) Unscrew the plug at the top of the boiler and fill the boiler with water.

(*b*) Replace the plug, open the safety valve, and allow the water to boil until all the air is expelled. Note the boiling point registered on the thermometer.

(*c*) Close the safety valve, still keeping the water boiling, and take simultaneous readings on the thermometer and pressure gauge.

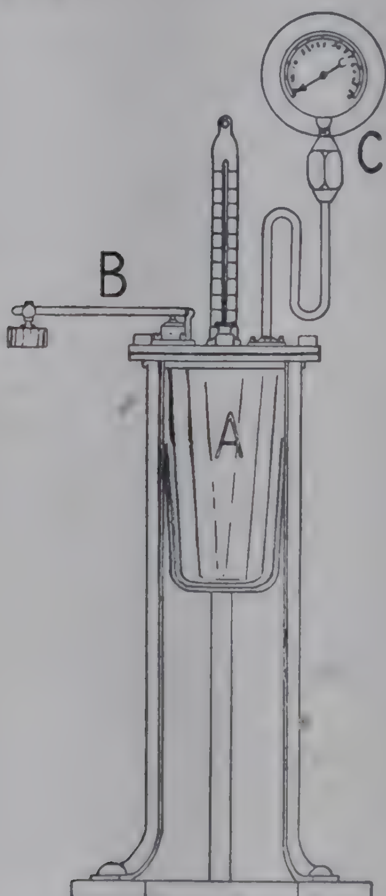

FIG. 51.—Papin's digester.

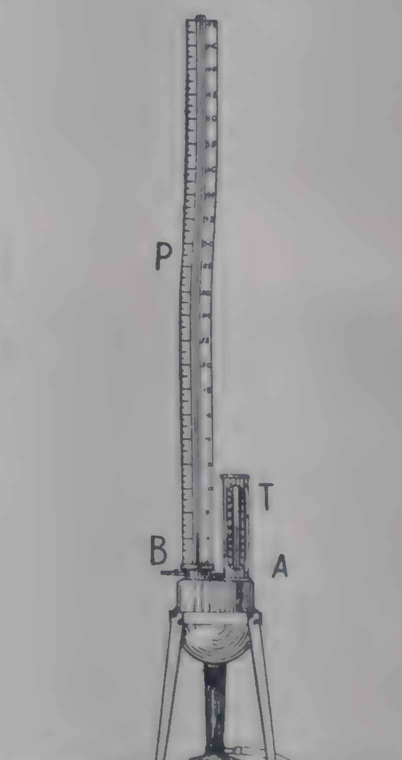

FIG. 52.—Marcet's boiler.

(*d*) Repeat these observations at intervals of 2° until the temperature reaches about 135° C.

(*e*) Take the burner away, and take a similar set of observations until the ordinary boiling point is reached.

(*f*) Enter the results in columns containing the temperatures and corresponding pressures.

(*g*) Plot two curves with temperatures as abscissae and the corresponding pressures as ordinates, one curve representing the results with the temperature rising and the other with the temperature falling.

60. Determination of the pressure of water vapour at temperatures above the normal boiling point (Marcet's boiler).

Apparatus.—The boiler (Fig. 52) contains a layer of mercury into which the manometer tube dips and above the mercury is poured water through the stopcock A. The thermometer T and the pressure gauge P are fastened with brass screw plugs. The pressure of the vapour forces the mercury up the barometer tube and the total pressure is given by adding this height of the mercury in the tube to the height of the barometer.

(*a*) Read the height of the barometer in centimetres, and reduce the reading to inches by dividing by 2.54.

(*b*) Fill the boiler with water through the stopcock A.

(*c*) Replace the stopcock, open the tap B and allow the water to boil until all the air has been expelled from the boiler.

(*d*) Close the tap B and take readings of pressure and temperature at intervals of two degrees rise in the thermometer.

(*e*) Continue the observations until the pressure gauge reads about 42 inches.

(*f*) Plot a curve with total pressure for ordinates and temperatures for abscissae.

Height of Barometer = 29.2 *inches.*

Temperature.	Gauge reading. (In inches.)	Total pressure. (In inches.)
214° C.	4·1	33·3
216° C.	5·7	34·9
......	......	......
......	......	......
......	......	......

Additional Notes on Chapter VIII.

(A) *Freezing by evaporation.*

Take a thermos flask and place some liquid sulphur dioxide at the bottom. Fit the flask with a cork containing three holes. Through one of these pass a test-tube containing mercury,

through the second a piece of narrow glass tube dipping into the SO_2, and into the third opening fit a short piece of tubing to serve as an outlet tube. By means of a water air-pump, draw a rapid stream of air through the liquid SO_2 until the evaporation is sufficiently rapid to withdraw heat from the surrounding air, and to freeze the mercury in the inner test-tube.

(B) *Spheroidal state.*

Take a concave copper plate and drill a fine hole at the centre of the base. Place a drop of water on the plate and it will be seen to leak through the hole. Now heat the plate strongly on a tripod stand and again place a drop of water on it. No leakage takes place owing to the cushion of vapour over the hole. On removing the source of heat the cushion of vapour disappears, the water gives off steam and simultaneously leaks through the opening.

(C) *Transition temperatures.*

In addition to the freezing point and boiling point there are certain temperatures at which definite physical changes take place, *e.g.* when octahedral sulphur changes to the prismatic form, or when a hydrate passes into the anhydrous salt. The temperatures at which these changes take place are known as transition temperatures or transition points, and they may be utilised in the calibration of thermometers. In order to detect the transition point of a substance two methods may be described.

(1) *The thermometric method.*

Weigh out about 30 grams of Glauber's salt (Na_2SO_4, $10H_2O$) into a thin test-tube containing a thermometer and stirrer. Support the test-tube in a beaker containing water and apply heat gradually, taking observations every minute of the temperature of the salt, until a temperature of 40° is reached. Then allow the temperature to fall slowly, and note the time and temperature until a reading of 26° C. is reached.

Plot a curve with the results, and it will be noted that at about 32° the variation in temperature is less than at any other point, and this will be the transition temperature.

(2) *The volume method.*

Take a 10 c.c. pipette and file off the bottom portion to within quarter of an inch of the bulb. Seal up the lower end of the pipette, and fill the instrument with powdered Glauber's salt.

Now fill up the air spaces between the salt particles inside by pouring in turpentine, warming the pipette so as to drive out the air bubbles. Allow the apparatus to cool and fix a graduated glass scale behind the liquid column in the upper tube. Support the pipette vertically in a beaker of water, and take readings of the volume of liquid at intervals of one minute. As in the previous experiment, raise the temperature to 40°, and then allow it to cool to 26°. Note that the volume increases or decreases at a regular rate, until a certain temperature is reached, when a sudden change in volume takes place. By plotting the observations on a curve the transition temperature may therefore be determined.

Note.—If a mixture of the two forms of the substance, *e.g.* Glauber's salt and pure anhydrous sodium sulphate, are placed together in the apparatus at the transition point, no change in volume will take place. This suggests a check method for the determination of the constant required.

Additional Exercises.

1 Determine the melting points of an alloy having the composition Pb_4Sn. Increase the proportion of tin in the alloy and note the effect on (*a*) the upper, (*b*) the lower melting point.

2. Determine the melting point of bismuth by plotting the cooling curve.

3. Find the melting point of paraffin, and, assuming the specific heat to be 0.71 in the fluid state and 0.67 in the solid state, determine the latent heat of the paraffin.

4. Find the specific heat of iron filings by means of Bunsen's ice calorimeter.

5. Determine the boiling point of benzene by the U-tube method.

6. Find the pressure corresponding to the boiling points of water at 100°, 95°, 90°, ..., 70°, and compare your results with those in the Tables, p. 199.

7. Repeat Expt. 6 for the temperatures 100°, 105° 110°, ..., 130°.

8. Determine the boiling points of water corresponding to the pressures 750, 700, 650, ..., 100 mm. of mercury.

9. Determine the boiling points of water at intervals of two inches (mercury) increase in pressure above that of the atmosphere until a total pressure of $2\frac{1}{2}$ atmospheres is reached.

10. Find the boiling point of a very small quantity of a given liquid. (Int. Sci. Hons. Lond. 1893.)

11. Determine the freezing point of the three solutions, A, B and C. (B.Sc. Pass Lond. 1894.)

12. Find the lowering of the freezing point of water produced with a 60 gram per litre solution of salt. (Int. Sci. Hons. Lond. 1894.)

13. Draw a curve showing the relation between the boiling point and strength of solutions of sodium chloride. (B.Sc. Hons. 1894.)

14. Determine the boiling points of a saturated and half-saturated solution of the given salt in water. (Int. Sci. Hons. Lond. 1898.)

15. Measure the specific heat of the given liquid by the method of cooling, and determine its temperature of solidification and its latent heat of liquefaction by plotting the curve of cooling. (B.Sc. Hons. Lond. 1900.)

16. Determine the melting point of the given solid, using the constant volume air thermometer. (Int. B.Sc. Pass Lond. 1907.)

17. Find the melting point of the given solid with the weight thermometer. (Ext. B.Sc. Pass Lond. 1908.)

18. Find the density of ice. (Ext. B.Sc. Hons. Lond. Chemistry, 1909.)

19. Determine the specific volumes of liquid and solid paraffin wax at its melting point. (Int. B.Sc. Hons. Lond. 1910.)

20. Find the molecular weight of the given substance by the raising of the boiling point and lowering of the freezing point. (Int. B.Sc. Pass Lond. 1911.)

21. Find the molecular weight of naphthalene by Beckmann's freezing point apparatus, weighing out about 0.15 gram of the substance and using benzene as the solvent.

22. Weigh out 0.2 gram of *p*-toluidine, and determine the molecular weight by the lowering of the freezing point of benzene.

23. Find the melting point of naphthalene by means of a cooling curve.

24. Determine the melting points of phenol and stearic acid by the capillary tube method.

25. Weigh out about 8 grams of mannitol ($C_6H_{14}O_6$) and dissolve in about 100 grams of water. Find the depression in the freezing point, and hence determine the molecular weight of the mannitol.

26. Compare the melting points of lead, tin, bismuth, and cadmium with the melting point of the 'fusible alloy' made by taking a mixture of equal parts of the four metals.

27. Standardise the given mercury thermometer by means of the following fixed points:

Melting point of ice 0° C.
Transition point of $Na_2SO_4 . 10H_2O$. 32°.4 C.
" " " $SrCl_2 . 6H_2O$. 61°.0 C.
Boiling point of water $100°.0+0.036(P-760)$.
" " " aniline $184°.2+0.051(P-760)$.
" " " naphthalene $218°.1+0.058(P-760)$.

Draw the calibration curve and use the thermometer to determine the boiling points of benzene, ethyl acetate, *p*-cresol and benzyl chloride.

28. Determine the molecular rise of the boiling point and the latent heat of vaporisation of potassium chloride in water solution.

29. Determine the latent heat of vaporisation of ethyl alcohol, and compare the result with that obtained from the formula $L=\frac{0.02T^2}{\alpha}$, where α and T are found from Tables.

30. Determine the transition temperatures for the salts $ZnSO_4 . 6H_2O$ and $ZnSO . 7H_2O$.

31. Determine the latent heat of fusion of naphthalene by means of the following observations:

(*a*) Find the melting point of the substance.

(*b*) Find the specific heat of the substance by heating a known weight to 60° C. in a sealed glass bulb and immersing it in aniline at a temperature of about 15° C.

(*c*) Find the specific heat of aniline in a fluid state by heating the bulb and contents to 120° C., and again immersing it in aniline at a temperature of about 85° C.

(*d*) Cool the aniline to about 15° C., heat the naphthalene to 120° C. and immerse it in the cold liquid. Calculate the latent heat of fusion, allowing for the thermal capacity of the bulb (specific heat of glass=0.19).

CHAPTER IX.

THERMOCHEMICAL PROCESSES.

61. Determination of the heat absorbed on dissolving a salt in water.

Apparatus.—Beaker, measuring cylinder, ammonium chloride, thermometer.

(*a*) Place 100 c.cs. of water in the beaker, which should be protected from radiation by a cotton wool enclosure.

(*b*) Counterpoise two filter papers on the balance and weigh out 2 grams of salt. Arrange about 10 separate portions of salt near the beaker.

(*c*) Place the first 2 grams of salt in the beaker, stir well until it has dissolved and then take the final temperature.

(*d*) Quickly add the next 2 grams and repeat the observations until the liquid is saturated with salt.

(*e*) Enter your results as in the table, and plot a curve, having percentage weights of salt as abscissae and temperatures of solution as ordinates.

Weight of water.	Weight of salt.	Percentage weight of salt in solution.	Temperature of solution.
100 grams.	2 grams.	1.96	15°.1 C.
,,	4 ,,	3.85	14°.7
,,	6 ,,	5.66	14°.2
......	......	......	......
......	......	......	......

62. Determination of the heat of solution of a solid.

Apparatus.—Calorimeter, thermometer, common salt, ammonium chloride.

The *heat of solution* is the amount of heat absorbed or emitted when 1 gram of a substance is dissolved in a solution of known strength. The *molecular heat of solution* is the heat absorbed or emitted when the molecular weight (in grams) of the substance is dissolved.

The simplest cases are those in which no hydrates are formed by the solution.

(*a*) Weigh the calorimeter and determine its water equivalent (c).

(*b*) Pour into the calorimeter 100 grams of water and note the temperature ($t_1°$).

(*c*) Weigh out 15 grams of ammonium chloride at the same temperature and transfer it to the calorimeter.

(*d*) Stir the solution and read the lowest or highest temperature registered ($t_2°$).

(*e*) Then if

H = molecular heat of solution of ammonium chloride,
s = specific heat of 15% solution of ammonium chloride,
M = molecular weight of ammonium chloride,

$$H = \frac{M(115s + c)(t_2 - t_1)}{15},$$

e.g. with NH_4Cl.

Wt. of aluminium calorimeter = 17.8 grams.

$c = 17.8 \times .212 = 3.77$. $m = 15$ grams.
$t_1 = 14°.1$. $t_2 = 3°.2$.
$M = 53.5$. $s = 0.84$.

$\therefore$ H (calculated) = -3903 calories.

(*f*) Find in the same way the heat of solution of a 20% solution of common salt.*

Specific heat of 20% solution of NaCl = 0.82.

* The accuracy of the method may be increased (*a*) by using a thermometer reading to $\frac{1}{10}°$, (*b*) by applying the cooling correction as in the determination of specific heat, (*c*) by finding the specific heat of the solution previous to the experiment, (*d*) by enclosing the dry salt in a thin glass bulb which is then placed in the calorimeter and crushed, so as to allow solution to take place.

Note.—Use either an aluminium or a thick copper calorimeter and wash it out well after the experiment, otherwise it will be attacked by the salts used.

63. Heat of combination of sulphuric acid and water.

Apparatus.—Burette, measuring cylinder, beaker packed in cotton wool, thermometer, sulphuric acid.

(*a*) Fill the burette with concentrated sulphuric acid.

(*b*) Pour out 100 c.cs. of water into the beaker. Run out 2 c.cs. of acid into this. Stir well and take the temperature.

(*c*) Add another 2 c.cs. of acid quickly and repeat the observation until the temperature of the mixture has reached 60° or 70° C.

(*d*) Calculate the percentage weight of sulphuric acid, assuming that

1 c.c. of water weighs 1 gram.
1 c.c. of acid weighs 1.8 grams.

E.g. if 2 c.cs. of acid are added it will weigh $2 \times 1.8 = 3.6$ grams, and the percentage weight of sulphuric acid present in the mixture is easily obtained by proportion, *i.e.*

$$\frac{3.6}{103.6} \times 100 = 3.4 \text{ per cent.}$$

(*e*) Enter your results in tables and plot a curve with percentage weights of sulphuric acid as abscissae and the temperatures of the mixtures as ordinates.

Weight of water.	Weight of H_2SO_4.	Percentage weight of H_2SO_4.	Temperature of mixture.
100 grams.	3.6 grams.	3.48	20°.5 C.
,,	7.2 ,,	6.72	22°.1
,,	10.8 ,,	9.75	26°.5
......	......	......	......
......	......	......	......
......	......	......	......

64. Determination of the heat of neutralisation.

Apparatus.—Neutralisation apparatus (Fig. 53). Normal solutions of hydrochloric acid, sulphuric acid, and sodium hydrate. (For method of making up these solutions consult a work on quantitative analysis.)

If an acid and a base are mixed together in the proportions of their molecular weights an increase in the temperature of the mixture is observed, and this is due to the heat of neutralisation. Generally if 1 molecule of an acid of the composition A . H is mixed with 1 molecule of a base of composition R . OH a quantity of heat Q is liberated by the combination

$$(ROH . Aq . AH . Aq) = (RA . H_2O . Aq).$$

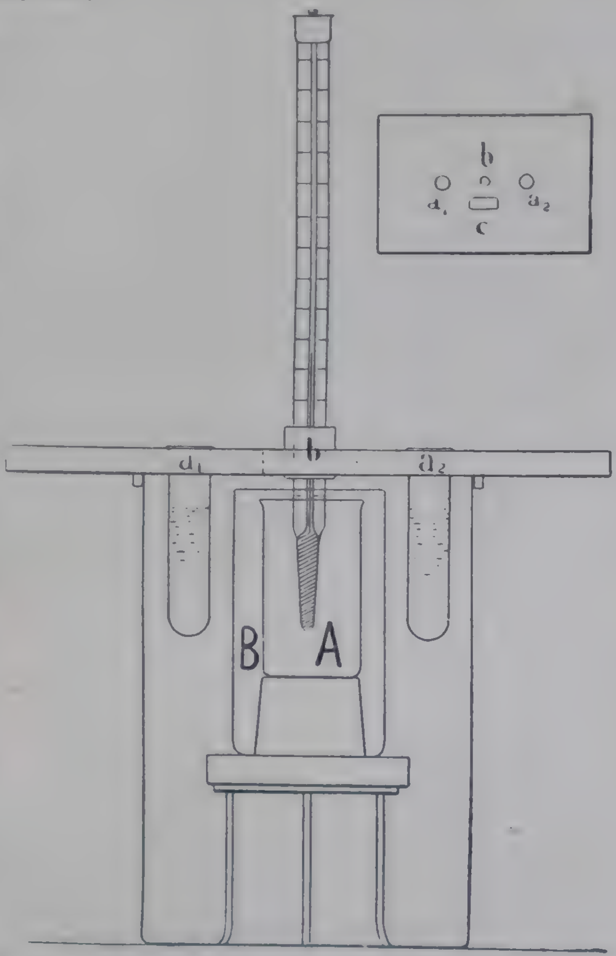

FIG. 53.—Apparatus to determine the heat of neutralisation of acids and alkalies.

This heat raises the temperature of M grams of the fluid mixture of specific heat s, from $t_1°$ to $t_2° = t°$ rise (say).

Then $$Q = M . s . t.$$

If the two solutions each contain a gram molecule, *i.e.* the molecular weight in grams dissolved, and made up to 1 litre with water, and equal volumes of these two solutions are mixed, the equation will still hold good, since $\frac{1}{n}$th molecule of acid is mixed with $\frac{1}{n}$th the molecule of base and the

amount of liquid heated is $\frac{1}{n}$th of M grams. Since the solutions are fairly dilute the specific gravity and also the specific heat of the solutions may be taken $=1$.

The heat of neutralisation is therefore given in calories by the equation

$$Q = 2 \cdot t.$$

(*a*) Fill the test-tube a_1 to a certain height with the normal hydrochloric acid solution. Fill the other test-tube a_2 to exactly the same height with the normal sodium hydrate solution.

(*b*) Place the test-tubes in the holes made in the wooden cover. Arrange the beaker A (Fig. 53) so that it rests inside the large vessel B, and lower the thermometer through the hole *b* until its bulb is in the middle of the beaker A.

(*c*) After waiting a few minutes for the liquids to take up the temperature of the apparatus, take out the test-tube a_1 and pour its contents carefully through the opening *c* into the mixing beaker. Read the temperature t_1° on the thermometer.

(*d*) Now take the test-tube a_2 containing the sodium hydrate solution and pour its contents into the mixing beaker. Take the temperature t_2° after waiting until the rise in temperature has taken place.*

(*e*) The rise in temperature is $t_2^\circ - t_1^\circ = t^\circ$. Calculate the heat of neutralisation $= 2t$.

(*f*) Empty the mixing beaker and repeat the experiment with the test-tubes filled to a higher mark.

(*g*) Find the heat of neutralisation of sulphuric acid and sodium hydrate.

$$\left.\begin{array}{ll}\text{First Expt.} & \left.\begin{array}{l} t_1^\circ = 13^\circ.87 \\ t_2^\circ = 20^\circ.02 \end{array}\right\} Q = 2 \times 6.15 = 12.3 \\ \text{Second Expt.} & \left.\begin{array}{l} t_1^\circ = 15^\circ.01 \\ t_2^\circ = 21^\circ.11 \end{array}\right\} Q = 2 \times 6.10 = 12.2 \end{array}\right\} \text{Mean} = 12.25.$$

* The accuracy of the experiment may be increased by using a Beckmann thermometer, and surrounding the calorimeter by a Dewar vacuum vessel.

65. Determination of the calorific value of fuel.

Apparatus.—The instrument known as Thompson's Calorimeter or Fuel Tester is used* (Fig. 54).

This instrument works on the assumption that the latent heat of steam is 967 (approximate) in British units, *i.e.* the heat required to convert 1 lb. of water at 212° F. into steam would suffice to raise the temperature of 967 lbs. of water 1° F. The apparatus is constructed to burn 2 grams of fuel in the midst of 1934 grams of water and hence the increased temperature of the water shows the number of grams of water

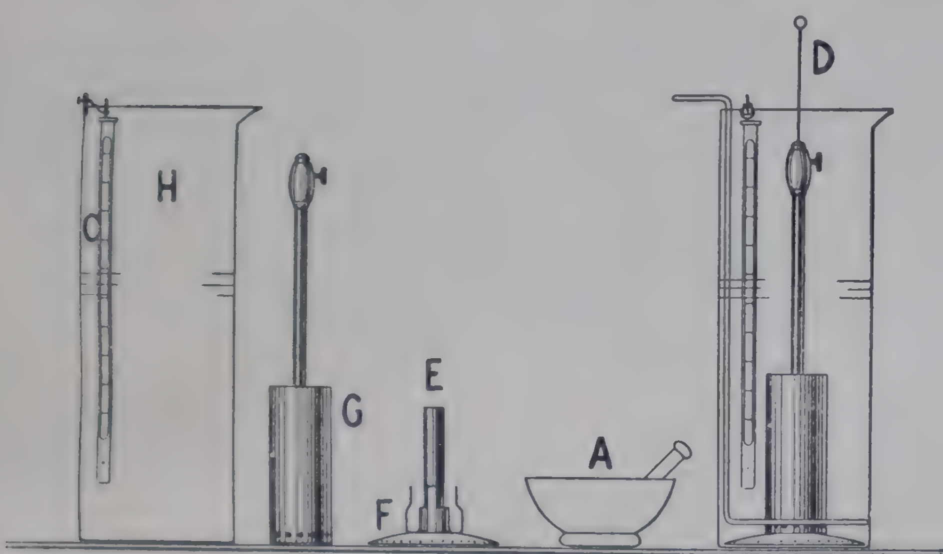

FIG. 54.—Thompson's fuel tester.

which 1 gram of the fuel is able to convert into steam, or, in other words, it gives the evaporative value of the fuel.

(*a*) Powder about 2 grams of the fuel in the iron mortar A and pass it through the sieve on to some white paper.

(*b*) Take about 26 grams of the oxygen mixture for combustion with the coal. This mixture consists of 3 parts potassium chlorate to 1 part potassium nitrate. Mix the

* In Darling's Fuel Calorimeter (see Darling's *Heat for Engineers*) the combustion of the fuel is started by electric ignition, and takes place in a nickel crucible placed in a combustion chamber through which a stream of oxygen is passing. The hot gases of combustion are allowed to bubble through the water surrounding the combustion chamber. The gas calorimeters of Boys and Junker are more elaborate but highly efficient.

powdered fuel and the oxygen mixture very intimately by means of a spatula.

(*c*) Compress this mixture into one of the copper furnaces E which is fitted in the socket of the brass plate F. Place about $\frac{1}{2}$ inch length of fuse on top of the powder.

(*d*) Fill the glass cylinder H up to the engraved mark with water (*i.e.* 1934 gms.) and take the exact temperature of this water by means of the thermometer C. The temperature of the water should be about 6° F. less than the temperature of the room. The addition of a little ice, if necessary, will secure this.

(*e*) Having the condenser cylinder G with its stopcock closed, light the fuse charge on F and *at once* cover it with the condenser, pressing the latter on the clutch springs of the base and immediately submerge the whole in the water contained in the glass cylinder. The whole operation must be done before the mixture in E is ignited.

(*f*) When combustion has ceased open the stopcock of the condenser and if air does not issue freely insert the long wire D and move the condenser up and down the water so as to cause the water both inside and outside the condenser to be at the same temperature. *Note the temperature of the water* as soon as possible and add 10 per cent. to the observed temperature, because 10 per cent. of the heat is absorbed by the instrument.

e.g. Grams of oxygen mixture = 26

Grams of coal = 2

Time of combustion = 50 seconds.

Rise of temperature of water + 10 per cent. = 14°.4 F.

Weight of water that would be evaporated at 212° F. per lb. of coal = 14.4 lbs.

British heat units generated per lb. of coal

$$= 967 \times 14.4 = \underline{13925.}$$

Value of fuel in calories $= 13925 \times \frac{5}{9} = \underline{7742.}$

Note.—The water must be poured into the vessel H up to the mark which corresponds to the temperature nearest to 6° F. less than that of the room.

Additional Notes on Chapter IX.

To find the solubility curve for sodium chloride.

Find the weight of a small evaporating basin and glass stirring rod. Place a flask of about 50 c.cs. capacity on a water bath at a constant temperature of 20° C., and add the salt gradually, shaking well until there is an excess of salt present. Allow the salt to settle, pour off about 10 c.cs. of solution into a weighed bottle, allow it to cool, and find the weight of the solution (w_1). Transfer the solution to the evaporating dish, carefully rinsing out the washings also into the dish, and evaporate to dryness on a water bath. Dry and weigh, thus finding the weight of salt (w_2) in the solution. Then the number of grams of salt which will dissolve in 100 parts by weight of water is given by $\frac{w_2}{w_1 - w_2} \times 100$. Repeat the experiment at temperatures of 40°, 60°, 80°, 100°, and plot a curve with weights of salt and temperatures.

Thermochemical quantities may be classified as follows:

(1) Heat of solution, dilution, and hydration.

(2) Heat of neutralisation.

(3) Heat of combustion.

(4) Heat of formation.

The heat produced in the thermochemical processes is expressed in ordinary calories, but generally the large calorie (K), which is equal to 100 calories, is taken as the unit of heat.

The heat changes are usually taken as arising from the reaction of one gram-molecule or one gram-equivalent of the substances under test, *e.g.* ($KClO_3$, Aq) = – 100.4K shows that 100.4 large calories are absorbed when one gram-molecule of potassium chlorate is dissolved in an excess of water (Aq).

Similarly (HClAq, NaOHAq) = 137.4K is the heat of neutralisation for dilute solutions of caustic soda and sodium hydrate. Again (C, O_2) = 969.6K indicates the heat of combustion produced when a gram-molecule of carbon is burnt in oxygen. The expression (N, H_3) = 118.9K shows the heat of formation when a gram-molecule of ammonia is formed from its elements.

The *heat of dilution* is the quantity of heat evolved or absorbed when a solution of one gram-molecule of a substance in water is diluted by a further given quantity of water (see Tables, p. 205). *E.g.* on diluting HCl to ($HCl \cdot 300H_2O$) 17.3 large calories per 36.5 grams of HCl are set free.

The *heat of hydration* is the quantity of heat evolved or absorbed when a gram-molecule of an anhydrous salt combines with water to form its crystalline hydrate, *e.g.*

$$(SrCl_2,\ 6H_2O) = 33.0K.$$

To find the heat of hydration of calcium chloride, (1) find the heat of solution of the anhydrous salt $CaCl_2$, (2) find the heat of solution of the crystallised salt $CaCl_2$, $6H_2O$. The difference between the two quantities of heat is the heat of hydration.

The *heat of formation* depends upon several of the above heat quantities, *e.g.* in the case of sodium chloride we require :—

(1) Heat of formation of (Na, O, H, Aq) from Tables, p. 204.

(2) Heat of formation of (H_2, O) from Tables, p. 204.

(3) Heat of formation of (H, Cl, Aq) from Tables, p. 204.

(4) Heat of neutralisation (h_1) of (NaOH, Aq . HCl, Aq) by experiment.

(5) Heat of solution (h_2) of (NaCl, Aq) by experiment.

From the equation

$$(Na,\ O,\ H,\ Aq) + (H,\ Cl,\ Aq) + h_1 = (Na,\ Cl,\ Aq) + (H_2,\ O).$$

Inserting the known values from Tables,

$$111.8 + 39.3 + h_1 = (Na,\ Cl,\ Aq) + 68.3)\ ;$$

$$\therefore\ (Na,\ Cl,\ Aq) = h_1 + 82.8.$$

Again, since $(Na,\ Cl,\ Aq) - (NaCl,\ Aq) = Na,\ Cl$;

$$\therefore\ h_1 + 82.8 - h_2 = (Na,\ Cl)$$

$$= \text{heat of formation of sodium chloride.}$$

Additional Exercises.

1. Find the heat absorbed by the solution of one gram of the given salt in water. (Int. Sci. Hons. Lond. 1890.)

2. Measure the heat developed by the mixture of definite quantities of H_2SO_4 and water. (B.Sc. Pass Lond. 1892.)

3. Measure the heat absorbed by the solution of definite quantities of KNO_3 and water. (B.Sc. Pass Lond. 1892.)

4. Find the heat developed when 60 c.c. of H_2SO_4 are mixed with a litre of water. (B.Sc. Pass Lond. 1894.)

5. Find the amount of heat developed when water and H_2SO_4 are mixed in the proportion of 10 to 1 by volume.

(B.Sc. Pass Lond. 1895.)

6. Measure the heat produced by the combustion of the given sample of fuel. (B.Sc. Pass Lond. 1900.)

7. Find the heat of solution of the given salt in water.

(Int. B.Sc. Pass Lond. 1908.)

8. Find the heat of dilution of a solution containing one gram molecule of sodium chloride from one concentration to another between the limits 4 times normal and $\frac{1}{4}$ normal, and express the results by means of a curve. (Int. B.Sc. Hons. Lond. 1908.)

9. Find the heat of solution of ammonium chloride in water.

(Int. B.Sc. Hons. Lond. 1908.)

10. Find the total change in volume per litre when sodium chloride is dissolved in water to form a saturated solution at the temperature of the room. Also determine the heat of solution of the salt.

11. Find the heat of formation of a normal solution of common salt in water. (Ext. B.Sc. Pass Lond. 1909.)

12. Find the heat of combination of one molecule of ammonium chloride with n molecules of water when $20 < n < 100$, and express the result by means of a curve.

(Ext. B.Sc. Hons. Lond. 1909.)

13. Measure the heat produced when 20 c.cs. of strong sulphuric acid are diluted with 20 c.cs. of water.

(Int. B.Sc. Pass Lond. 1910.)

14. Find the molecular heat of solution of the given salt in water, stating the dilution for which your result applies.

(Ext. B.Sc. Pass Lond. 1911.)

15. Determine the molecular heat of solution of Na_2SO_4, $n.H_2O$ ($n=25$) on diluting to Na_2SO_4, $x.H_2O$ ($x=100$, 150, 200, 250, 300).

16. Determine the transition temperature at which anhydrous sodium sulphate, the hydrated salt, and a saturated solution can co-exist in a state of equilibrium. (Board of Education, 1911.)

17. Determine the relation between the boiling point of a solution of the given salt and the quantity of salt dissolved in 100 grams of water. (Board of Education, 1909.)

18. Determine the heat of solution of a 25 per cent. solution of potassium chloride. (Make a previous determination of the specific heat of the solution.)

19. Find the heat of hydration of copper sulphate, stating the amount of dilution.

CHAPTER X.

PROPERTIES OF VAPOURS.

66. Saturated and unsaturated vapours.

Apparatus.—Glass tubing, small bent pipette, mercury, turpentine, methylated spirits, ether.

(*a*) Take a piece of glass tubing about 5 mms. diameter and 85 cms. in length. Close one end in the bunsen flame. Fill the tube with clean dry mercury and invert it over a bowl of mercury, so as to form a simple barometer. Note the height of the mercury above the level in the reservoir.

Make a bent pipette, having a bulb in the middle. Fill this with water and blow gently so as to cause one or two drops of water to ascend through the mercury into the vacuum of the barometer. Notice that the water disappears and the vapour formed exerts a pressure, causing the mercury column to be depressed. Note the height of the mercury.

Force a little more liquid to the top, when the mercury column is depressed still further, showing that the space at the top is still unsaturated with vapour. When, however, some water remains above the mercury the height cannot be reduced any further, showing that the vapour is exerting its maximum pressure. The vapour is now said to be *saturated.*

The difference between the present height and the original height of the mercury column gives the *vapour pressure* of the liquid at the temperature of the room.

(*b*) Refill the barometer tube after carefully drying it, and find the vapour pressure of turpentine, methylated spirits and ether.

(*c*) Cut off a portion of the tube so that its length is now about 80 cms. and repeat Expt. 66 (*a*) with water.

In the case of the unsaturated vapour it will be found that the pressure differs from the previous result and is greater, owing to the diminished volume, the vapour thus behaving after the manner of a gas.

When the vapour, however, is saturated, the pressure is exactly the same, showing that in the latter case the pressure is independent of the volume of vapour.

An unsaturated vapour, as stated above, possesses properties similar to those of a gas, and we should therefore expect it to conform to the laws of gases (Chap. V.).

67. Determination of the relation between the pressure and volume of an unsaturated vapour at constant temperature.

Apparatus.—Boyle's law apparatus (Fig. 27).

(*a*) Remove the plug of the stopcock and half fill the hole in it with plaster of Paris or electric cement (Fig. 55). Replace the plug and attach a tube filled with water to the end of the burette by means of a piece of rubber tubing. When the plug is turned completely round, a small quantity of water will enter the burette without, however, allowing any connection with the atmosphere. The tube B (Fig. 27) must previously be lowered until the level of the mercury in B is more than 76 cms. lower than that in A, *i.e.* until $(H - h)$ has a positive value.

FIG. 55.—Section of plug for burette used in Expt. 67.

The water vapour will now enter and depress the mercury in A. The experiment consists in noting the volume (V) of this vapour and the corresponding reading of $(H \pm h)$ which gives the pressure (P) to which the vapour is subjected.

(*b*) Plot the different values for the various readings of P and V on a curve in the same manner as in the Expt. on Boyle's law, p. 41.

68. Measurement of the pressure of saturated water vapour at different temperatures (below 100° C.)

Apparatus.—The apparatus (Fig. 56) consists of an inner glass tube A about 32 inches in length and filled with mercury. This is immersed in a wooden trough B containing mercury. An outer glass tube C is connected up to a water tank so that water at different temperatures may be passed in. This tube C rests on a small wooden ledge D at its lower end, while the upper end is fastened to an upright board by means of rubber bands. A thermometer attached to the inner tube registers the temperature of the enclosure.

FIG. 56.—Apparatus for the determination of vapour pressures below 100° C.

(*a*) Pass a few drops of water into the tube A by means of a curved pipette, being careful to prevent air passing up with the water.

(*b*) Note the height of the mercury above the level of the mercury in the trough B by means of a metre scale. Read the barometer and also the temperature of the room.

(*c*) Gradually heat the water in the boiler and when its temperature is about 25° C. allow the water to run through the outer tube C. Note simultaneously the temperature of the water in C and the height (h) of the mercury column in A.

(*d*) Repeat these observations when the temperature of the enclosure is 35°, 45° ... 100° C.

(*e*) Tabulate the results thus :

Height of barometer (H) = 75.7 cms.

Temperature of room (t_1) = 15°.1 C.

Experiment.	Height of mercury in A (h).	Vapour pressure $=(H-h)$.	Temperature of enclosure (t_2).
1	74.0 cms.	1.7 cms.	22°.6 C.
2	71.5	4.2	37°.1
3	68.9	6.8	45°.5
4	62.4	13.3	58°.6
......	......	......	......
......	......	......	......

(*f*) Plot a curve having for ordinates the values of the vapour pressures $(H-h)$ and the corresponding temperatures (t_2).

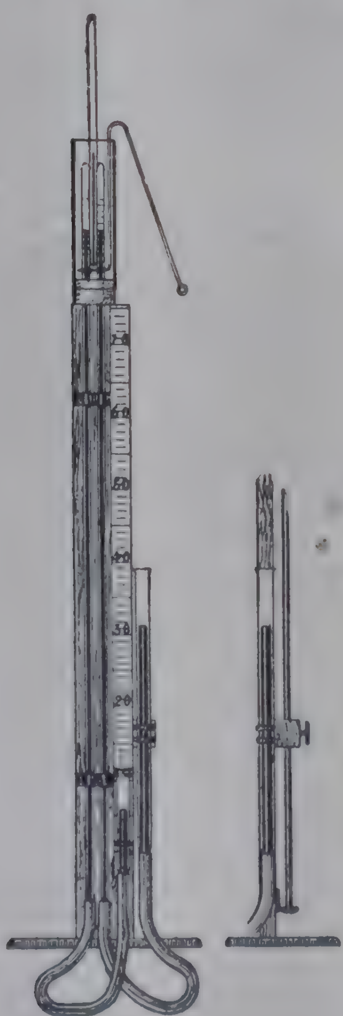

FIG. 57.--Alternative form of apparatus for determination of vapour pressure.

Corrections.—To obtain accurate results the following corrections are required:

1. The height of the barometer (H) must be reduced to 0° C. by means of the formula:

$$H_0=\frac{H}{1+\alpha t_1}$$

where H = observed height

t_1 = temperature of room

α = coefficient of expansion of mercury = 0.000181.

This correction is most noticeable for temperatures below 50° C., *e.g.* at 30° the correction will be about 0.4 cm., while the vapour pressure itself is only about 3.2 cms.

2. Similarly for each observation the height of the mercury in the tube must be reduced to 0° C. by using the formula:

$$h_0=\frac{h}{1+\alpha t_2}$$

where h = observed height

t_2 = temperature of water.

3. Plot a second curve with values of (H_0-h_0) instead of $(H-h)$ and with corresponding values of t_2.

Note.—When a liquid boils, the maximum vapour pressure corresponding to the boiling point is equal to the external pressure, therefore it is evident that the results from the determination of boiling points at low pressures (Expt. 58) will be similar to those obtained in the above experiment.

A neat alternative form of apparatus is shown in Fig. 57, where two syphon barometers are arranged side by side : one of them contains some of the liquid in the closed tube, and the vapour pressure is measured by adjusting the mercury in the closed tubes to exactly the same height. The difference in level of the mercury in the open tubes gives the required vapour pressure. The upper ends of the closed tubes are surrounded by a piece of combustion tubing fitted with a rubber stopper and containing water at the various temperatures.

69. Determination of the vapour pressure of a liquid between 0° C. and 50° C.

Apparatus.—Two similar barometer tubes, bell jar, retort stand, mercury, mercury trough, thermometer.

Between 0° C. and 50° C. the vapour pressure of aqueous vapour is less than 10 cms. of mercury, therefore it is only necessary to surround the upper part of the tube.

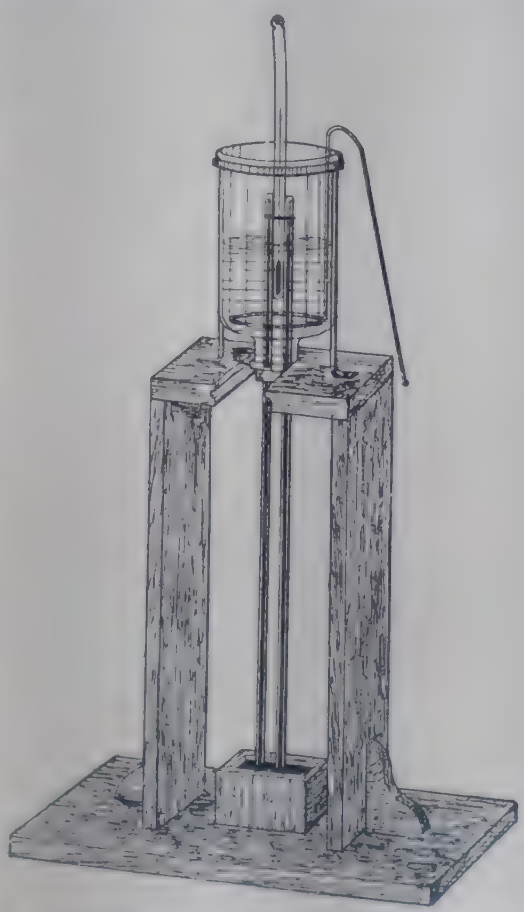

FIG. 58.—Apparatus for the determination of vapour pressures below 100° C.

(*a*) Take a glass bell jar and fit into it a two-hole rubber stopper ; obtain two similar pieces of glass tubing each about 80 cms. long and close one end of each. Fill the tubes with mercury and invert

them over a mercury trough. Pass a few drops of water to the top of the first tube so as to saturate the empty space with water vapour. The second tube will serve as a barometer.

Push the upper ends of the tubes through the stopper so that they are to the centre of the bell jar. Fasten a thermometer to each tube and support the bell jar on a retort stand or shelf (Fig. 58). A stirrer is provided which is bent down so as to enable the experimenter to stir the liquid from below.

(*b*) The bell jar is first filled with a mixture of ice and water at a temperature of 0° C. The difference in the height of the mercury column is measured with a glass millimetre scale or a cathetometer. Warm water is added gradually and a series of observations are taken at intervals of 2° or 3° C. until the limit of 50° C. is reached. Great care must be taken to prevent a bubble of air entering the barometer tube when it is filled with mercury, otherwise the expansion of this air will cause the mercury to fall more than in the vapour tube, and discordant results will be obtained.

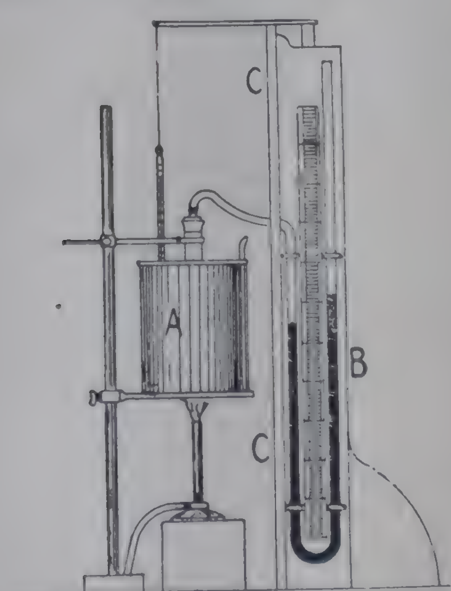

FIG. 59.—Apparatus for the determination of the vapour pressure of alcohol vapour.

70. Determination of the pressure of alcohol vapour at different temperatures.

Apparatus.—The alcohol is placed in a flask * immersed in the metal tank A (Fig. 59). This flask is connected to a manometer B and the pressure is measured by the difference in level of the mercury in the two limbs. The manometer is screened from the heat by a wooden partition CC lined with asbestos on the side near the flame. A stirrer and thermometer are placed in the water inside A.

* An air thermometer bulb connected to the manometer with pressure tubing is perhaps the best to use.

(*a*) Take out the rubber stopper and drop into the flask a small tube containing alcohol. Connect the rubber tubing with the flask.

(*b*) Fill the tank with water, stir well and read the temperature and also note the manometer readings. From the latter obtain the difference in level (h) and add to this the height of the barometer (H). The pressure of the alcohol vapour and air together is $H+h$.

(*c*) Raise the temperature of the water in the tank and take observations of the manometer at intervals of 5° C.

(*d*) Enter the results thus:

Height of barometer (H) = 74.9 cms.

Temperature of room = 14°.3 C.

1. Temperature (t).	2. Difference of level (h)	3. Pressure of alcohol+air ($H+h$).	4. Pressure of air (calculated).	5. Pressure of alcohol vapour.
18°.2 C.	4.8 cms.	79.7 cms.	75.9 cms.	3.8 cms.
23°.2	7.3	82.2	77.2	5.0
28°.2	10.4	85.3	78.5	6.8
......	......	......	......	......
......	......	......	......	......
......	......	......	......	......

The first three columns are filled in as stated above.

In column 4 the pressure (P_2) of the air at any temperature (t_2) is calculated from the formula

$$\frac{P_2}{P_1}=\frac{273+t_2}{273+t_1}$$

where P_1 is the pressure of the atmosphere at the temperature of the room (t_1), *i.e.* P_1 is the same as H above.

The results in column 5 are the difference between the results of columns 3 and 4.

(*e*) Plot a curve with temperatures as abscissae and corresponding vapour pressures of alcohol as ordinates.

71. Hygrometry.

The subject of hygrometry deals with the measurements with regard to the moisture in the air. The *relative humidity*, or *hygrometric state*, of the air is the ratio of the mass of aqueous vapour actually present in a given volume of the air to the mass of vapour required to saturate that volume at the same temperature.

The latter quantity can be obtained from Tables while the mass of aqueous vapour in a given volume of air can be determined by the chemical hygrometer (Fig. 60).

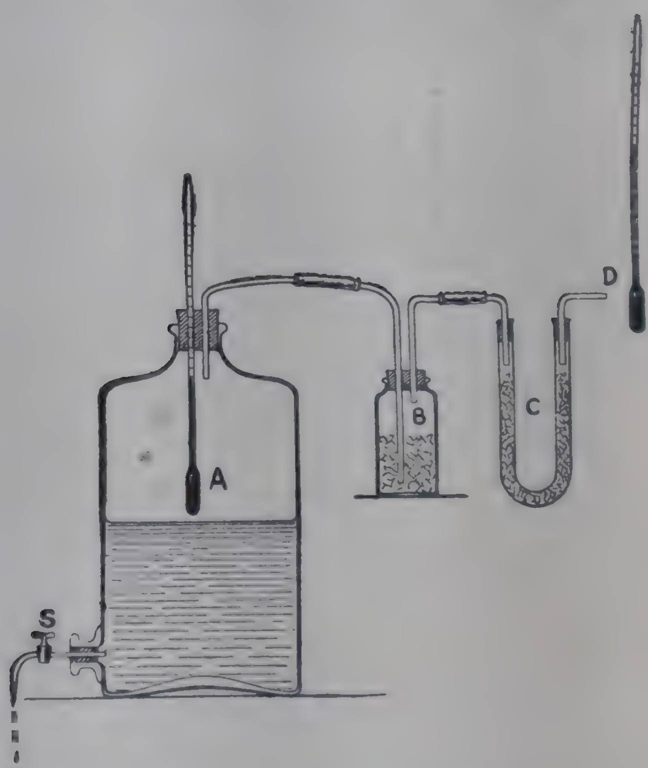

FIG. 60.—Chemical hygrometer.

Use of the chemical hygrometer.—The U-tube C contains pumice stone soaked in strong sulphuric acid and each end is closed with a small piece of glass rod fixed on with rubber tubing, so that the moisture of the atmosphere does not affect it during the weighing. The bottle B contains more pumice soaked in sulphuric acid in order to protect the U-tube from the moisture from the water in the aspirator A.

(*a*) The aspirator is filled with water and the tube C is accurately weighed. The glass rods on the latter are now removed and the tube is connected up with the apparatus.

(*b*) The tap of the aspirator is turned and a definite volume of water, say 5 litres, is run off. The same volume of air will consequently be drawn through the tube C and the moisture will be absorbed by the sulphuric acid. The U-tube is now detached, the glass rod again fixed on the end, and weighed again. The difference in weight gives the amount of moisture in 5 litres of air at the temperature of the room.

From this result we can calculate the mass (m) of moisture in 1 litre of air. If M is the mass of saturated vapour in 1 litre of air at the same temperature (from Tables) the relative humidity is given by $\frac{m}{M}$ approximately. This result is not correct for two reasons:

1. The air in contact with the water is saturated while the air drawn through the apparatus is unsaturated.

2. The temperature of the air in the aspirator as measured by the thermometer on A is different from the temperature of the outside air as read off at D.

The *dew point*. This may be defined as the temperature at which the aqueous vapour actually present in the air is sufficient to saturate it. The dew point is most important, since we can obtain, by means of it, the mass of vapour actually present in a given volume of air.

A dew point hygrometer is an instrument for determining the dew point by cooling a surface until the dew begins to be deposited.

72. Determination of the dew point by the aluminium hygrometer.

(*a*) This very simple and at the same time very accurate instrument consists of an aluminium cup A (Fig. 61) about 2 inches diameter and 4 inches in height. The vessel is placed on the table and the temperature is taken with the thermometer B, which reads to 0°.1 C. A sheet of glass is placed in front of the cup in order to protect it from the heat of the observer's

body. After filling the vessel about half-way with tap water, pieces of ice are dropped in and the contents vigorously stirred with a wire-gauze stirrer until dew begins to appear, when the dew point is read off on the thermometer. The water is then poured out and the experiment repeated three or four times, the mean of the results being taken. The dew point can be determined to an accuracy of 0°.2 C. within three minutes from the commencement of the experiment.

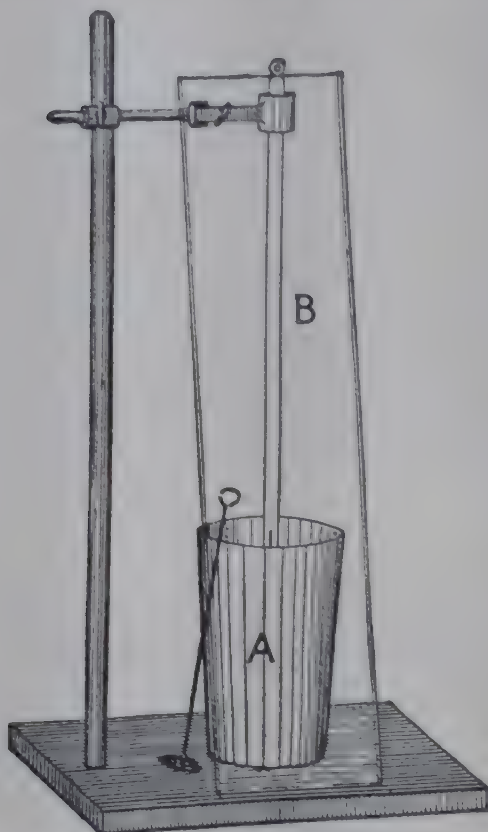

FIG. 61.—Aluminium dew point apparatus.

73. Determination of dew point by Daniell's hygrometer.

Apparatus.—Daniell's hygrometer, muslin, ether.

Daniell's hygrometer (Fig. 62) is one of the oldest forms of dew point instruments. It consists of two bulbs A and B connected by a bent glass tube. The bulb A is half filled with ether, the rest of the instrument containing nothing but ether vapour. The bulb B is covered with muslin and can be cooled by dropping ether upon it. This condenses the ether vapour inside B, and more ether distils over from A to take its place.

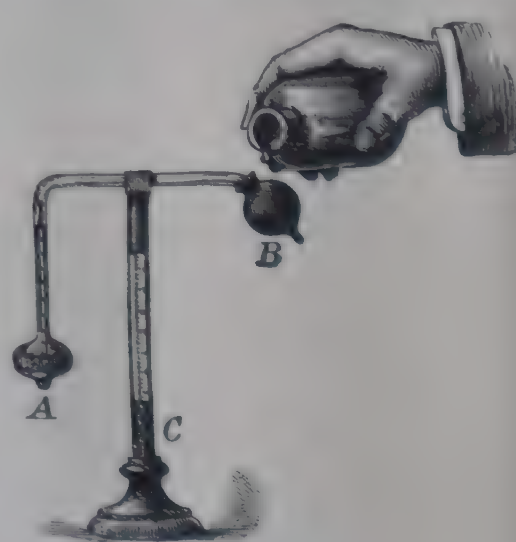

FIG. 62.—Daniell's hygrometer.

The heat required to evaporate this ether is taken from the liquid in A, and its temperature gradually falls until a thin film of dew appears on the outside of the bulb. A delicate thermometer inside A registers this dew point and a thermometer on the stem C gives the actual temperature of the air.

(*a*) Take observations of the dew point and the temperature of the air in three different rooms.

(*b*) From the Tables (p. 199), calculate the pressure of aqueous vapour in each case and arrange the results in some convenient form.

74. Determination of the relative humidity by Regnault's hygrometer.

Apparatus.—Regnault's hygrometer, aspirator, ether.

As previously stated, the humidity of the air is the ratio of the mass of vapour actually present in a given volume of air to the mass of vapour which this volume would contain if saturated at the existing temperature. This ratio is the same as that of the ratio of the vapour tension in the air (p_1) to the maximum vapour tension which the vapour could exert at the same temperature (p_2). The percentage humidity is given by $\frac{p_1}{p_2} \times 100$.

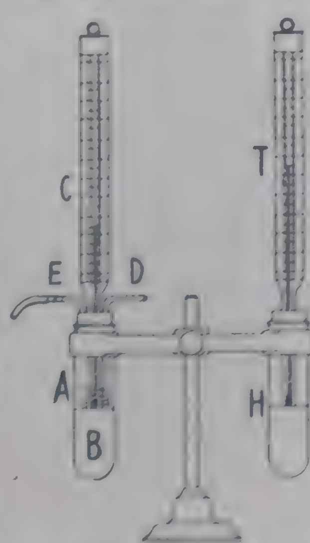

Fig. 63.—Regnault's hygrometer.

Regnault's hygrometer consists of a glass tube A with the lower part surrounded by a thin silver tube B (Fig. 63). Through the stopper in A passes a thermometer C, a glass tube D dipping into the ether inside, and short tube E which is used to draw air through the apparatus. The silvered tube H is placed alongside for comparison, and the thermometer T inside gives the temperature of the atmosphere.

(*a*) Pour ether into B so as to cover the bulb of the thermometer.

(*b*) Connect an aspirator to E so as to draw air through the ether. Some of the liquid evaporates and by this means the external air is cooled down to a point at which the moisture condenses on the metal surface outside the hygrometer. When the surface just begins to be dimmed with moisture stop the stream of air and read the temperature on C.

(*c*) Repeat the observation several times and take the average of these (t_1).

(*d*) Read the temperature of the atmosphere (t_2) registered by T.

(*e*) From the Tables (p. 199), find the maximum vapour pressure (p_1) at the temperature (t_1) and also the maximum vapour pressure (p_2) at the temperature of the atmosphere (t_2). Calculate the percentage humidity $\frac{p_1}{p_2} \times 100$.

e.g. $t_1 = 9^\circ.4$ C.

$t_2 = 17^\circ.9$ C.

Maximum vapour pressure at 10° C. = 9.17 mms.
Maximum vapour pressure at 9° C. = 8.57

Difference for 1° C. = 0.60
Difference for 0°.4 = 0.24

∴ Maximum vapour pressure at 9°.4 = 8.81 (p_1).

Maximum vapour pressure at 18° C. = 15.36 mms.
Maximum vapour pressure at 17° C. = 14.42

Difference for 1° C. = 0.94
Difference for 0°.9 = 0.85

∴ Maximum vapour pressure at 17°.9 = 15.27 (p_2).

$$\text{Relative humidity} = \frac{8.81}{15.27} \times 100$$

$$= \underline{57.7} \text{ per cent.}$$

75. The wet and dry bulb hygrometer.

Apparatus.—Wet and dry bulb hygrometer, Regnault's hygrometer.

The wet and dry bulb hygrometer consists of two thermometers (Fig. 64) hanging side by side, to one of which is attached a piece of loose cotton dipping into a vessel of water. The water rises up the cotton by capillary attraction and the bulb of the wet thermometer is kept in a moist state.

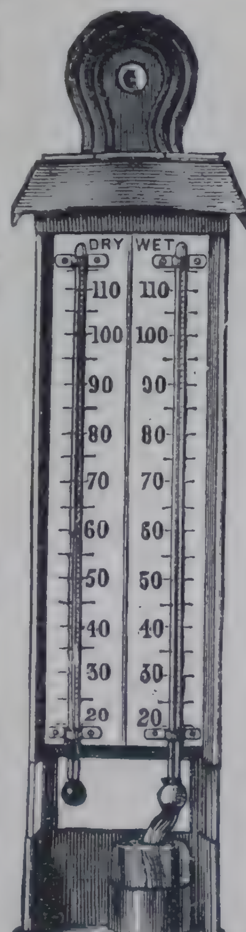

Fig. 64.—Wet and dry bulb thermometer.

It can be proved that if:

t = temperature of the dry bulb thermometer.
t_1 = temperature of the wet bulb thermometer.
F = maximum pressure of water vapour at the temperature t.
f = pressure of the water vapour in the air.
H = barometric height in mms.

Then $f = F - AH(t - t_1)$ where A is the constant of the instrument.

(*a*) Note the temperature of the air (t) on the dry bulb thermometer. Also note t_1 on the wet bulb thermometer.

(*b*) Read the barometric height in mms. (H).

(*c*) By means of Regnault's hygrometer find the dew point, *i.e.* the temperature at which the air would be saturated if it contained as much water vapour as it does at the present temperature (t).

(*d*) From the Tables (p. 199), find the maximum pressure of the water vapour at the dew point. This will be the same as (f), the pressure of the water vapour actually present in the air.

(*e*) From the same Tables obtain (F), the maximum pressure of water vapour at the temperature t. Both f and F are measured in mms. of mercury.

(*f*) Substitute the values found for f, F, H, t, and t_1 in the above formula and thus find the value of A.

e.g. Height of barometer = 753 mms.
Dry bulb reading $(t) = 18°.9$ C.
Wet " " $(t_1) = 15°.5$ C.
Dew point = $12°.9$ C.
Max. Vap. Press. at $18°.9$ (F) = 16.26 mms.
" " $12°.9$ (f) = 11.09 mms.

$$\therefore\ 11.09 = 16.26 - 753 \times A(18.9 - 15.5)$$

$$A = \frac{5.17}{753 \times 3.4} = \underline{0.00202.}$$

Note.—If the constant of the hygrometer has once been determined the pressure of water vapour can easily be determined by reading t, t_1, and H and obtaining the values of F from Tables.

76. Determination of the density of dry air.

The *absolute density* of a substance is the mass of unit volume. In the case of gases and unsaturated vapours the density is sometimes defined as the ratio of the mass of a certain volume of the gas or vapour at a given temperature and pressure to that of an equal volume of dry air at the same temperature and pressure.

Apparatus.—Glass sample tube similar to that used in Expt. 24.

(*a*) The tube (Fig. 33) is first cleaned and dried. Connect one end to a U-tube containing calcium chloride and the other to an air pump. Draw air gently through the tube for a few minutes, close the stopcock adjacent to the air pump and after waiting for the tube to assume the temperature of the air, close the other stopcock. Detach the drying tube and weigh the sample tube with the contained dry air. Also note the height of the barometer and the temperature of the room. Connect the sample tube again with the air pump and exhaust the tube as completely as possible after opening one of the stopcocks. Now close this stopcock and weigh the tube, from which result obtain the mass (m) of the air inside.

(*b*) To find the volume of this air immerse the tube in a tank of water and open the lower stopcock, when the water will rush

in and almost fill the tube. Arrange the tube so that the level of the water is the same inside and out, then close the stopcock, take out the tube, dry the outside, and weigh.

(*c*) Subtract from the weight the previous weight when exhausted and thus obtain the mass of water inside and hence the volume (V) of the dry air contained at the commencement. Then the density of the air is given by the ratio $\frac{m}{V}$.

77. Mass of a given volume of moist air.

If a volume V (litres) of moist air is measured at a pressure P and temperature $t°$ C. and if p is the pressure of aqueous vapour present, then the entire volume of air may be supposed to consist of:—

(1) A volume V of dry air at pressure $(P-p)$ and temperature t. The mass is

$$m_1 = V \times 1.293 \times \frac{273}{273+t} \times \frac{P-p}{760} \text{ grams.}$$

(2) A volume V of aqueous vapour at pressure p and temperature t. The mass is

$$m_2 = \frac{5}{8} V \times 1.293 \times \frac{273}{273+t} \times \frac{p}{760} \text{ grams,}$$

since the ratio of the densities of moisture and dry air is $\frac{9}{14.4} = \frac{5}{8}$ approximately.

The total mass of the moist air (M) is the sum of m_1 and m_2 and is given by the equation

$$M = V \times 1.293 \times \frac{273}{273+t} \times \frac{P - \frac{3}{8}p}{760} \text{ grams.}$$

78. Determination of vapour density by Victor Meyer's method.

The absolute density of a body is the mass per unit volume. In determining the vapour density by V. Meyer's method, a known mass of the volatile substance is vaporised, and

the volume of vapour yielded is measured by the quantity of air which the vapour displaces.

The volume of air is corrected to normal temperature and pressure.

Apparatus.—The apparatus consists of:

(1) An outer heating jacket A (Fig. 65) containing water which serves to heat the vapour tube. This is usually made of glass, but a copper hypsometer may be used.

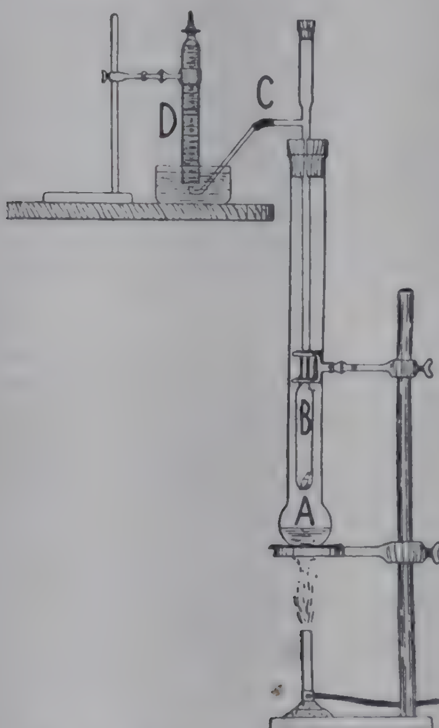

FIG. 65.—Apparatus for the determination of vapour density by V. Meyer's method.

(2) An inner vapour tube B furnished with a delivery tube C. It is best to file C in two pieces and join them up with a thin piece of rubber tubing. This makes the tube more flexible and less liable to breakage.

(3) A measuring burette D filled with water and inverted in a vessel of water.

(*a*) See that the outer tube A contains some water, which must be kept boiling, so that the steam may escape from the loose cork at the top. Thoroughly dry the inner tube B, place it inside the heating jacket and fit a cork in the open end. Place the delivery tube under the surface of the water.

(*b*) As soon as no more bubbles escape from the delivery tube C, the cork is loosened at the top of the vapour tube B, which is now ready for the experiment.

Clamp the measuring burette in position, having previously filled it with water.

(*c*) Weigh the small glass tube and stopper provided, fill it with the given liquid, insert the stopper, and weigh again quickly. This gives the weight of liquid used (m).

(*d*) Quickly uncork the vapour tube B, drop in the small glass tube, and replace the cork.

(*e*) The liquid will begin to vaporise, and the vapour will displace air which will pass into the measuring burette. As soon as no more bubbles escape remove the delivery tube C out of the water.

(*f*) The measuring tube is carefully transferred to a tall cylinder of water (the thumb being placed over the end to prevent the contents escaping), and immersed until its contents have gained the temperature of the water. The burette is then lowered until the water inside and out is at the same level.

(*g*) The volume of the air (v) in cubic centimetres is read off, also the temperature of the water (t), the height of the barometer (P), while from Tables (p. 199) the tension of water vapour (p) at $t°$ is obtained.

Since the mass of liquid $= m$.

$$\left.\begin{array}{r}\text{and corrected volume reduced}\\ \text{to } 0°\text{ C. and 760 mms.}\end{array}\right\} = v \times \frac{273}{273+t} \times \frac{P-p}{760};$$

∴ density compared with hydrogen

$$= \frac{m}{v} \times \frac{273+t}{273} \times \frac{760}{P-p} \times \frac{1}{0.0000896}.$$

Since 1 cubic centimetre of hydrogen weighs 0.0000896 gram.

Example.

Weight of ether taken - -	= 0.073 gram.
Temperature of water - -	= 21.5° C.
Volume of air displaced - -	= 25.3 c.cs.
Barometric pressure - -	= 719 mms.
Tension of aqueous vapour at 21°.5 from Tables - - -	= 19 mms.

$$\therefore \text{ vapour density} = \frac{0.073 \times 760 \times 294.5}{25.3 \times 700 \times 273 \times 0.0000896} = 36.75.$$

79. Determination of vapour density by Hofmann's method.

This method, unlike that of V. Meyer's, enables us to determine the vapour densities of substances which decompose at temperatures below their boiling point *at ordinary atmospheric pressure.*

A weighed quantity of the substance is placed in the Torricellian vacuum of a barometer, which is then heated to a constant temperature by means of a steam jacket. If V is the volume of the vapour from the substance, h the height of the mercury in the tube, and P = barometric height, $t°$ = temperature of boiling water (from Tables).

The volume of the vapour reduced to 0° C. and 760 mms. is

$$V \times \frac{P-h}{760} \times \frac{273}{273+t°},$$

and if m is the mass of the liquid its density compared with hydrogen (1 c.c. weighs 0.0000896 gram) is

$$D = \frac{m}{V} \times \frac{273+t}{273} \times \frac{760}{P-h} \times \frac{1}{0.0000896}.$$

Apparatus.—Glass tube closed at one end containing mercury and inverted over mercury trough, wide combustion tubing, boiler, liquid, small density tube.

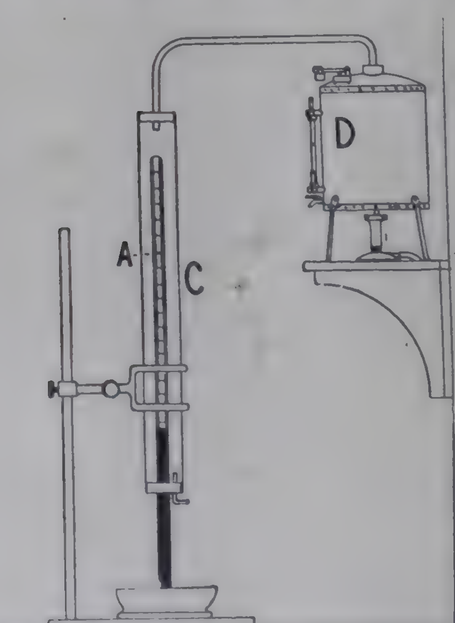

FIG. 66.—Apparatus for determination of vapour density by Hofmann's method.

(*a*) Fill the inner tube A (Fig. 66) with mercury and invert it over a trough of mercury. The Torricellian vacuum will form at the top. Now measure with a metre scale the height of the column of mercury in the tube, P′. Reduce this to 0° C. by dividing by

$$(1 + 0.000181\ t_0)$$

where t_0 is the temperature of the column as read on the thermometer attached to it.

$$\frac{P'}{1+0.000181\ t_0} = P \text{ in the formula.}$$

(*b*) Place the outer tube C over the inner tube. Weigh the small vapour density tube empty, then fill it with a liquid and weigh again. The difference in weight gives m the mass of liquid used.

(*c*) Slip the tube and contents (having previously loosened the stopper) under the mouth of the tube A. The tube will rise to the top and partially vaporise, thus pushing down the column of mercury.

(*d*) Connect up the outer jacket C with a steam heater D, and allow steam to pass through until all the liquid has been vaporised and the column of mercury in A remains at a constant level.

(*e*) Measure as before the height of the mercury column, say h', and reduce it to zero by dividing by $(1+0.000181\,t)$ where t is the temperature of the column as read on the attached thermometer.

$$\frac{h'}{1+0\cdot000181\,t}=h \text{ in the formula.}$$

(*f*) Read off the volume V of the gas in A. The tube is graduated in cubic centimetres.

(*g*) Substitute these values in the formula and thus calculate the density of the given substance.

e.g. for chloroform – $CHCl_3$,

$$\begin{aligned} m&=0.099 \text{ gram,}\\ V&=45.1 \text{ c.cs.,}\\ P&=744 \text{ mms.,}\\ h&=321 \text{ mms.,}\\ t&=100^\circ \text{ C.;}\\ \therefore\ D \text{ (calculated)}&=\underline{60.1}. \end{aligned}$$

Note.—The inner tube A should have a length of about 80 cms. and a capacity of about 200 c.cs.

A piece of wide combustion tubing will serve for the steam jacket.

Additional Notes on Chapter X.

(1) *Experiment* 69. In order to maintain a constant level of the mercury in the barometer cistern, the wooden trough may be replaced by a closed glass bottle, and a second bottle containing mercury placed alongside. The latter is closed by a rubber stopper through which the longer limb of a siphon passes, and

also a second tube which terminates above the mercury. The short limb of the siphon is in the cistern with its end opposite the zero mark on the barometer. Mercury is forced into the cistern until the end of the short limb of the siphon is immersed. The mercury is then allowed to siphon back into the bottle, and will cease to flow when the level in the cistern reaches the extremity of the short limb of the siphon. This adjustment is made for each observation of the vapour pressure.

(2) *Lambrecht's Polymeter* is a combination of thermometer and hair hygrometer, each provided with Centigrade and Fahrenheit scales showing elastic force of vapour in millimetres, relative humidity, and the difference between the dew point and the temperature of the air. A separate dew point apparatus consists of a drum to which a thermometer and polished disc are attached. Ether is introduced into the drum, and air is forced through by means of a rubber bulb.

(3) In V. Meyer's apparatus a pad of asbestos or dry sand may be placed in the Meyer tube to break the fall of the small tube containing the liquid under test. To avoid the use of the cork at the top of the apparatus a special form of apparatus has been designed by Schüller, in which a glass tube bent at an angle is ground into the top of the Meyer tube and the small tube rests within this. By giving the former tube a half turn the small tube slips to the bottom of the apparatus.

If substances of higher boiling point have to be vaporised, the water in the outer jacket must be replaced by liquids of correspondingly higher boiling point, *e.g.* aniline B.P. 182°; ethyl benzoate B.P. 211°; amyl acetate B.P. 260°, etc. Owing to the increase in the vapour pressure of mercury, Hofmann's apparatus should not be used for temperatures above 250° C.

Additional Exercises.

1. Find the vapour pressure of ether vapour at intervals of 5° from 0° C. to 30° C.

2. Determine the vapour pressure of water at intervals of 5° from 0° to 50° C. Compare the results with those in the Tables, p. 199.

3. Determine the vapour density of alcohol vapour by Meyer's method. (B.Sc. Pass Lond. 1892.)

4. Draw a curve showing the connection between the temperature and vapour pressure of water. (B.Sc. Hons. Lond. 1893.)

5. Find the vapour density of chloroform by V. Meyer's method. (B.Sc. Hons. Lond. 1893.)

6. Find the vapour pressure of water, ether, and a 1% by volume solution of H_2SO_4 at the temperature of the room. (B.Sc. Hons. Lond. 1894.)

7. Find the vapour pressure of water from 80° to 100°. (B.Sc. Hons. Lond. 1895.)

8. Measure the vapour pressure of the air by means of a chemical hygrometer. (B.Sc. Hons. Lond. 1897.)

9. Verify Dalton's law of the relation between the temperature and pressure of a vapour.

10. Determine the vapour density of the given volatile solid. (B.Sc. Pass Lond. 1900.)

11. Determine the density of chloroform vapour by Dumas' method at two temperatures. (Int. B.Sc. Hons. Lond. 1907.)

12. Plot a curve showing the relation between pressure and boiling point of water for pressures less than atmospheric. (Ext. B.Sc. Hons. Lond. 1909.)

13. Determine the variation of saturation vapour pressure of the given liquid with temperature. (Int. B.Sc. Pass Lond. 1911.)

14. Determine the vapour pressure of a given substance for a number of temperatures by the method of finding the boiling point under an artificial atmosphere, and plot a curve. (Int. B.Sc. Hons. Lond. 1911.)

15. Find the effect of temperature on the vapour pressure of water near 100° C. (Ext. B.Sc. Pass Lond. 1911.)

16. Find the dew point and calculate the density of air at the place of experiment. Density of dry air at 0° C. and 760 mm. is 0.001293. Density of water vapour is $\frac{5}{8}$ that of dry air. (Board of Education, 1909.)

17. Determine the density of the given liquid by measuring the density of its vapour. (Board of Education, 1906.)

18. Find the vapour density of methyl iodide by weighing 0.4 gram of the substance and using the V. Meyer apparatus.

19. Determine the vapour density of the given liquid by Hofmann's method. (Board of Education, 1911.)

20. Find the vapour density of acetic acid at temperatures of 150° C. and 225° C., using the V. Meyer apparatus. Weigh out 0.15 gram of the substance for each experiment and use aniline and quinoline as heating liquids.

21. Determine the vapour tension of the given solution at the temperature of the air by passing air through a long tube containing wool moistened with the solution, and finding the weight of water contained in a measured volume of air.

(Board of Education, 1911.)

CHAPTER XI.

ELECTRICAL METHODS OF MEASURING TEMPERATURE.

The best known of the applications of electrical methods to the measurement of temperature are (*a*) the metallic resistance thermometer, (*b*) the thermo-couple.

80. Electrical resistance thermometer.

In the case of pure metals the electrical resistance varies with the temperature according to a definite law.

If R_t = resistance of a metallic wire at $t°$ C.

R_0 = resistance at $0°$ C.

The relation can be expressed by the equation

$$R_t = R_0(1 + at + bt^2)$$

where a and b are constants which vary slightly for each metal.

For any two definite temperatures t_1 and t_2

$$R_1 = R_0(1 + at_1 + bt_1^2)$$
$$R_2 = R_0(1 + at_2 + bt_2^2)$$

Hence, if we determine R_0, R_1 and R_2, we can find the constants a and b from the above equations. In practice the temperatures t_1 and t_2 are the boiling points of water and sulphur respectively.

The metal usually employed in this kind of thermometric work is platinum, the resistance of which for a given temperature is found to be unchanged with time. Platinum is also suitable on account of its chemical purity and for the fact that it can be subjected to very high or very low temperatures.

Apparatus.—A resistance thermometer (Fig. 67), which consists of a coil of pure platinum wire A wound on a thin mica frame B and enclosed in a glass or porcelain tube C. The ends of the wire are connected to thick platinum leads, the ends of which are joined to flexible copper wires. In order to eliminate the effect of heat on the leads a pair of duplicate leads are inserted in the tube. The resistance of these 'dummy leads' is subtracted from the resistance of the coil and its proper leads in order to determine the resistance of the coil. In addition to the resistance thermometer will be required a freezing point apparatus, hypsometer, porcelain vessel containing sulphur, post office box, accurate reflecting galvanometer (constant of galvanometer about 10^{-8}).

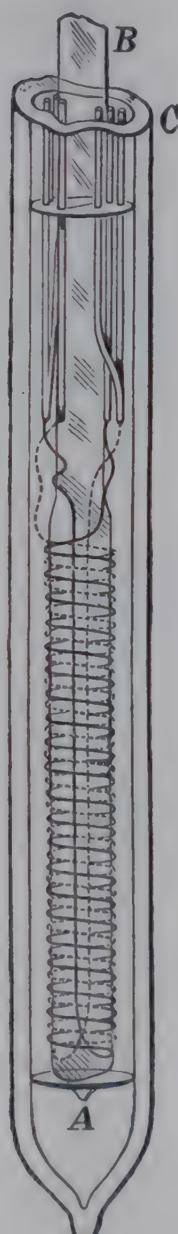

FIG. 67.—Platinum resistance thermometer.

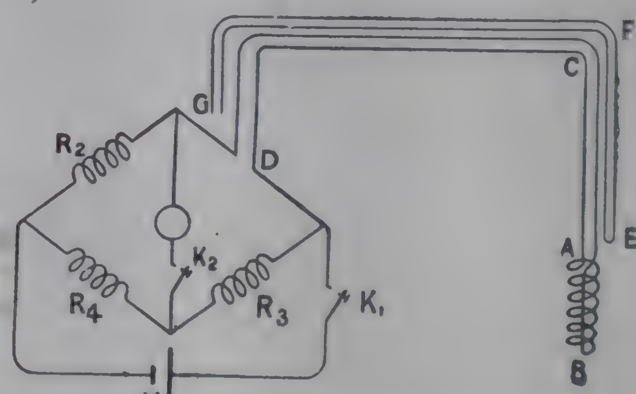

FIG. 68.—Diagram showing Wheatstone bridge connections for a platinum resistance thermometer.

(i.) Calibration of a platinum thermometer.

(*a*) *To find* R_0 *i.e. the resistance of the thermometer at the temperature of melting ice.* Immerse the glass tube up to the top in a vessel containing melting ice. Connect up the thermometer in the Wheatstone bridge, as in the following diagram (Fig. 68). AB is the platinum thermometer, V is the battery, K_1 battery key, K_2 galvanometer key, R_2, R_4 are ratio coils, R_3 is a bridge coil. Find the resistance necessary to

produce a balance, using the method of swings and interpolating. All connections should be made with thick pieces of copper wire, and further, the battery key should only be depressed momentarily in order to avoid the current heating the platinum thermometer. Having found the resistance of the duplicate leads, the difference between this and the previous result gives the resistance of the thermometer (R_0).

(*b*) *To find* R_1 *i.e. the resistance of the thermometer at the temperature of boiling water.* Take the thermometer out of the ice and place it in the hypsometer (see Fig. 3) so that it is surrounded by the steam from boiling water. Note the barometric height, and calculate the boiling point from Tables. When the resistance of the platinum thermometer has become steady determine its value, as in Expt. 80 (*a*), and so obtain R_1.

(*c*) *To find* R_2 *i.e. the resistance of the platinum thermometer at the boiling point of sulphur.*

The boiling point of sulphur at 760 mms. pressure is 444°.53 C., and a difference of 10 mms. pressure makes a difference of 0°.82 C. in the boiling point.

The platinum thermometer is placed in a hard glass or porcelain tube A (Fig. 69) containing sulphur. An asbestos cone B, filled with asbestos wool, is placed as a cover at the top, and a smaller perforated asbestos cone C serves to prevent the condensed sulphur clinging to the sides of the thermometer tube. The sulphur is gradually heated until it is boiling, and when the platinum thermometer has reached the temperature of the surrounding vapour its resistance (R_2) is determined. The boiling point of sulphur (t_2) is calculated from the previously observed barometric height.

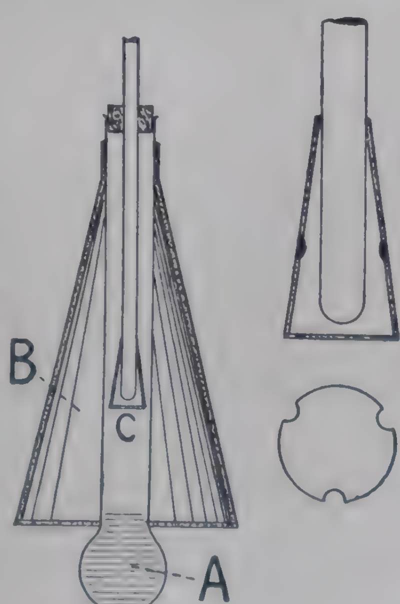

FIG. 69.—Apparatus for the determination of the boiling point of sulphur.

(*d*) Substitute the values for R_0, R_1, R_2, t_1, and t_2 in the equations

$$R_1 = R_0(1 + at_1 + bt_1^2),$$
$$R_2 = R_0(1 + at_2 + bt_2^2),$$

and calculate the values of *a* and *b*. From the results calculate the values of R for various values of *t*.

(*e*) Plot the results on a curve taking values of *t* as abscissae and values of R as ordinates.

The form of the curve is a parabola with its vertex at or near $-273°$ C. (absolute zero).

e.g. Height of barometer $= 759.5$ mms.

Boiling point of sulphur $= 444°.5$ C.

$$R_0 = 2.619 \text{ ohms.}$$
$$R_1 = 3.618 \text{ ohms.}$$
$$R_2 = 6.832 \text{ ohms.}$$

Substituting these values in the equation

$$R_t = R_0(1 + at + bt^2)$$

we have

$$3.618 = 2.619(1 + 100a + 10000b)$$
$$6.832 = 2.619(1 + 444.5a + 444.5^2 b).$$

Solving this simultaneous equation

$$a = +0.003865.$$
$$b = -0.000000506.$$

The equation for the thermometer is therefore

$$R_t = 2.619(1 + 0.003865t - 0.000000506t^2)$$
$$= 2.619 + 0.01013t - 0.000001352t^2.$$

Hence by substitution

$$R_{-50} = 2.110 \text{ ohms.}$$
$$R_{-100} = 1.592 \quad ,,$$
$$R_{-150} = 1.069 \quad ,,$$
$$R_{-200} = 0.539 \quad ,,$$
$$R_{+500} = 7.346 \quad ,,$$
$$R_{+1000} = 11.397 \quad ,,$$

With these results a curve can be plotted showing the temperature for any given resistance of the thermometer.

81. The thermo-couple.

Apparatus.—Wires of various materials, heater, reflecting galvanometer.

(*a*) Take an iron wire and a nickel wire, each about No. 32 B.W.G., and solder the two together at one end. Pass the soldered junction through a cork in a test-tube immersed in water and connect the free ends of the wires to the terminals of a reflecting astatic galvanometer having a constant of about 10^{-8}. Now gradually raise the temperature of the junction of the wires by heating the water surrounding the test-tube. The galvanometer will show a deflection which increases as the temperature rises. The current of electricity thus produced is known as a thermo-electric current, and the two wires form a thermo-electric couple or thermo-couple.

(*b*) Solder wires of copper, brass, iron, nickel, manganin, and platinum to a brass ring A (Fig. 70) placed inside a test-tube B.

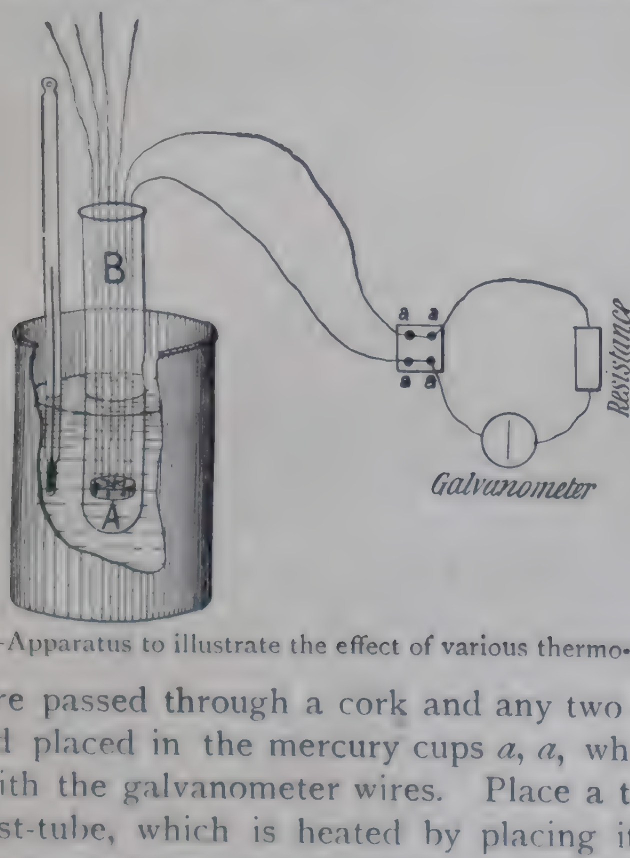

FIG. 70.—Apparatus to illustrate the effect of various thermo-couples.

The wires are passed through a cork and any two of them can be taken and placed in the mercury cups *a*, *a*, which are also connected with the galvanometer wires. Place a thermometer inside the test-tube, which is heated by placing it in a water bath. The mercury cups are shielded so as to keep them at

a constant temperature. Keeping the test-tube at a temperature of 100° note the deflections produced by various combinations of wires forming thermo-couples. Note that the deflection produced by each pair of metals is different, the greatest deflection being produced by the iron-nickel combination.

The above experiments would appear to indicate that a thermo-electric couple is a convenient instrument for the measurement of temperature, provided that we are acquainted with the relation between the temperature and the thermo-electric E.M.F., *i.e.* the difference of potential produced by the temperature difference of the hot and cold ends of the couple.

(*c*) Take the iron-nickel couple, and, keeping the temperature of the cold junction constant, gradually heat the other junction from the temperature of the room up to 100° C. Take galvanometer readings every 10°; these readings will be proportional to the thermo-electric E.M.F. (E).

(*d*) Plot a curve having temperatures of the hot junction as abscissae and corresponding deflections as ordinates.

The curve is practically a straight line curve showing that in the case of a nickel-iron couple the relation between the thermo-electric E.M.F. (E) and the temperature of the hot junction (t) may be represented by the equation $E = a + bt$ where a and b are constants.

(*e*) Repeat Expt. 81 (*c*) with a copper-manganin couple and notice that the observations when plotted give a parabolic curve. Its equation is

$$E = at + bt^2.$$

Summing up the results of Expts. 81 (*c*) and (*d*) it will be seen that by taking a thermo-couple composed of any two dissimilar metals, which have a good thermo-electric E.M.F., temperatures can easily be measured after the couple has been once standardised. The cold junction should be kept at a constant temperature and the other junction placed successively in (1) melting ice (2) steam, or the vapour from boiling sulphur, and from the general equation

$$E = at + bt^2$$

the constants may be determined and the curve plotted as in the case of the platinum thermometer.

ADDITIONAL NOTES ON CHAPTER XI.

(1) We have already noted the methods for measuring temperature by means of the expansion of a metal bar and the alteration in volume of a liquid or gas (Chapters III., IV., and V.).

There remain three methods involving the observation of electrical or radiation effects, viz.:

(*a*) The alteration produced by heat on the electrical resistance of a metallic conductor.

(*b*) The variation in the electromotive force set up at the junction of two dissimilar metals when a difference of temperature is applied to the junction.

(*c*) The radiation given out by a hot surface. This is referred to more fully in Chapter XIII.

(2) A *thermo-electric pyrometer* is simply a thermo-couple of platinum and platinum-iridium or platinum-rhodium, which gives an E.M.F. of about 500 microvolts with the junctions at 0° and 100° respectively. A galvanometer of the d'Arsonval type is usually employed with a German silver coil having a resistance of 500 ohms. The galvanometer has two scales giving the readings in degrees Centigrade and the E.M.F. in microvolts. The thermo-couple is protected by a double porcelain tube and an outer steel tube. For high temperatures the relation between temperature and E.M.F. is represented by the equation

$$\log E = a \log t + b,$$

where a and b are constants.

(3) To standardise a thermo-couple the junction is first placed in boiling water and the galvanometer reading reduced to a convenient division by means of a resistance in the circuit. The temperature of the cold junction is noted. The hot junction is then immersed in baths of known temperatures, *e.g.* steam 100°, solidifying lead 327° C., solidifying zinc 419°, solidifying antimony 632°, and the galvanometer deflections observed in each case. A curve is then plotted with temperature differences against galvanometer deflections.

(4) The platinum resistance thermometer may be constructed with a capacity for observing temperatures in specific heat, latent heat, melting points, or molecular weight determinations.

Its range of temperature from 200° to 900° C. is wide enough for use in all kinds of technical work. The difference between the reading (Pt) on the platinum thermometer and the air thermometer (t) is given by the equation

$$t - Pt = \delta\left\{\left(\frac{t}{100}\right)^2 - \left(\frac{t}{100}\right)\right\},$$

where δ is a constant and is nearly equal to 1.5.

Additional Exercises.

1. Plot a curve showing the relation between the deflections of a galvanometer and the temperature of the hot junction of a given thermo-couple.

2. Standardise the given couple for 0° C., 100° C., and the boiling point of sulphur. Draw the calibration curve, and from the curve determine the galvanometer deflection for the melting point of lead (326° C.). Verify your results by experiment.

3. Find the melting point of the given alloy by means of a thermo-couple.

4. Using a nickel-iron couple with a brazed junction calibrate it as in Expt. 81 and determine with it the melting point of zinc.

5. Find the errors at different points of the high temperature mercury thermometer by immersing it side by side with a standardised thermo-couple in the apparatus used for the melting point of an alloy (Expt. 49).

6. Standardise a platinum resistance thermometer at three given temperatures and determine the constants of the instrument.

7. Determine the melting point of common salt and of chloride of magnesium given the melting point of tin (238° C.) and of zinc (415° C.) and using the platinum-rhodium pyrometer.

(B.Sc. Hons. Lond. 1899.)

8. In the case of a gold thermometer it was found that $R_0 = 1.085$, $R_{50°} = 1.277$, $R_{100°} = 1.463$. Assuming that the resistance varies with the temperature according to the parabolic law $R_t = R_0(1 + \alpha t + \beta t^2)$ calculate the values of α and β and plot the resistance curve by taking various values of t. Find from the curve the absolute zero of the thermometer.

9. Plot a curve of E.M.F. for the given thermo-couple, and determine from your results the melting point of the given substance. (Int. B.Sc. Hons. Lond. 1906.)

10. Plot a curve showing the relation between the E.M.F. of the given thermo-couple and the temperature of one junction as it is raised from 0° C. to 100° C., the other junction being maintained at 0° C. (Int. B.Sc. Pass Lond. 1909.)

11. Given a platinum resistance thermometer and Callendar-Griffiths bridge, find the melting point of the given solid. (Int. B.Sc. Hons. Lond. 1909.)

12. Measure the temperature at the hottest part of the given flame electrically. (Ext. B.Sc. Pass Lond. 1909.)

13. Determine the melting point of the given crystalline body (sodium sulphate) by means of the platinum resistance thermometer. (Int. B.Sc. Hons. Lond. 1911.)

14. Determine by means of a thermo-couple the eutectic mixture of lead and tin, *i.e.* the mixture with the minimum melting point.

15. Standardise the thermo-couple by means of the following fixed points :

Boiling point of aniline 180° C.,
" " quinoline 239° C.,
" " sulphur 444° C.,

and hence determine the transition temperatures of tin, bismuth, and cadmium.

CHAPTER XII.

CONDUCTION OF HEAT.

82. Transference of heat.

Heat may be transferred from one point to another in three different ways, viz. :

(i.) **Conduction.** In this case the heat is transferred from one particle to another in the direction of the decrease in **temperature, but** no visible motion of the particles takes place, *e.g.* the passage of heat along a poker from the end placed in the fire.

(ii.) **Convection.** This takes place when heat is transmitted through the substance of a body by means of the motion of the particles themselves, *e.g.* in heating a liquid with a source of heat below the containing vessel.

(iii.) **Radiation** occurs when heat is transferred without the intervention of a material medium, *e.g.* the heat of the sun.

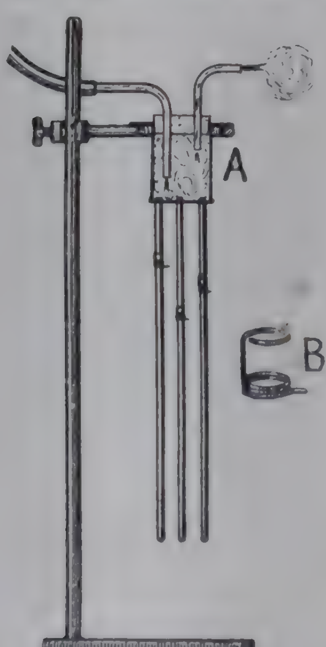

FIG. 71.—Apparatus for the comparison of the relative conductivities of bars by Edser's method.

83. Determination of the relative thermal conductivities of different rods (Edser's method).

Apparatus.—The metal can A (Fig. 71) is fitted with a metal rim and the bottom of the can drilled so as to receive a number of metal rods, each of the same diameter and length. The rods are soldered flush with the inside surface. Each rod is fitted with a small index B made of a copper or brass wire and shaped as in the figure.

(*a*) Slip an index over each rod and arrange the single ring of the index in contact with the bottom of the can. Melt a little

paraffin wax round each index, and when it is solid it will support the rings.

(*b*) Support the vessel in the ring of a retort stand and fit the open end with a cork through which passes a steam delivery tube. When the steam has been passing through for some minutes the wax will melt and the indexes will slip down until they arrive at points where the wax will just solidify, *i.e.* where the temperature is the same in each case. After this stationary stage has been reached measure the distance (l) of each index from the bottom of the can and the results will determine the relative conductivities (k) since k is proportional to l^2.

The apparatus will work satisfactorily if the rods are electroplated so as to eliminate the different nature of the surfaces. Care must also be taken that the wax is spread evenly over each index before starting the experiment.

84. Comparison of conductivities of two metal bars (Forbes's method).

Apparatus.—Two metal bars AA and BB (Fig. 72) are each 32 ins. in length and 1 inch in diameter. Each bar is electro-

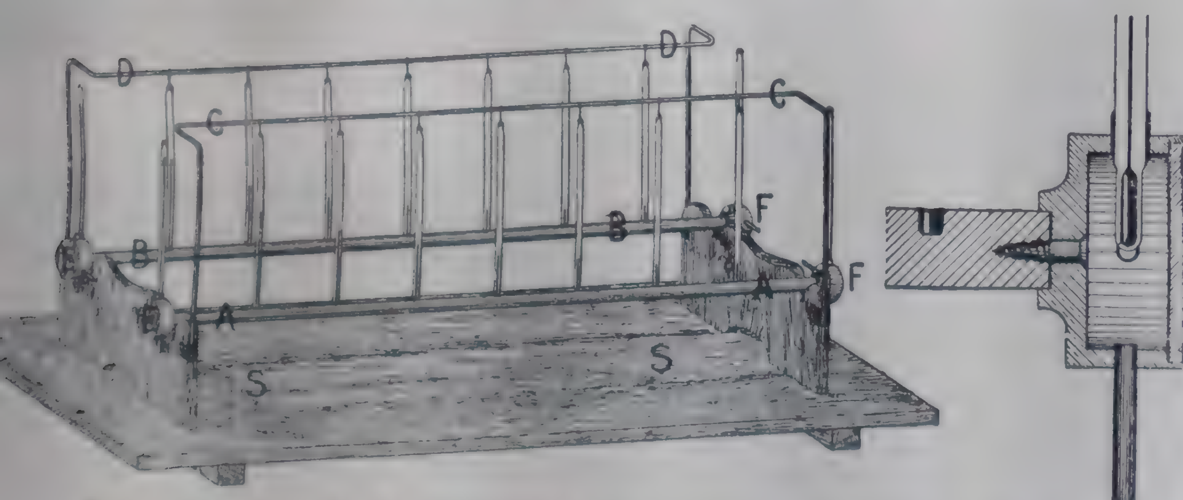

FIG. 72.—Apparatus for the comparison of conductivities of two bars by Forbes's method.

plated so as to have the same surface emissivity. Circular holes $\frac{3}{8}$ inch in depth and $\frac{3}{16}$ inch diameter are sunk at intervals of

4 inches along the bars, and thermometers with specially made bulbs are placed in the holes in order to observe the temperature at different points. The thermometers are surrounded with mercury and are suspended from the supports CC and DD. Brass boxes are fitted to each end of the bars, the boxes E, E being connected by a T-piece of rubber tubing to a steam heater, while the other two F, F, may be connected to a supply of cold water or they may be left open to the air. (An enlarged view of one of the brass boxes is given in the figure.) The heat from E, E may be prevented from being radiated to the thermometers by interposing a metal screen, while radiation between the two bars is similarly prevented by a separating screen of asbestos. The two bars fit into grooves on the wooden stand SS.

(i.) **Experimental observations.**—(*a*) The thermometer holes having been filled with mercury the bars are simultaneously heated at one end by passing steam through the boxes E, E. It will probably be found that the other ends are sufficiently cool without passing water through the boxes.

(*b*) Notice that after a few minutes the first two or three thermometers on each bar are rising in temperature, but that the rise is not the same for each bar. After a further interval the heat wave will reach the end of each bar and the thermometers will indicate a diminishing temperature as we proceed along each bar from the heated ends.

(*c*) After the steam has been passing for about an hour the variable state described above has ceased and the bars are in a stationary state, *i.e.* when each section of a bar loses by radiation from its surface exactly the same amount of heat as it receives by conduction from the adjacent section which is at a higher temperature.

(*d*) Record the readings of the thermometers in each bar, and accurately note the temperature of the surrounding air on a thermometer placed horizontally about 12 inches below the level of the bars. The excess of temperature of each point on the bar can now be obtained.

(*e*) Enter the results thus :

$$\text{Temperature of air}\begin{cases}\text{beginning of experiment} = 18^\circ.1\ \text{C.}\\ \text{end of experiment} = 18^\circ.3\ \text{C.}\end{cases}$$

Position of Thermometer.	First Bar.		Second Bar.	
	Temperature.	Excess of Temperature.	Temperature.	Excess of Temperature.
0	99°.0	80°.9	99°.0	80°.9
1	68°.4	50°.3	53°.0	34°.9
2	53°.2	35°.1	35°.8	17°.7
3	43°.0	24°.9	26°.8	8°.7
4	36°.1	18°.0	22°.5	4°.4
5	31°.1	13°.0	20°.5	2°.4
6	27°.9	9°.8	19°.4	1°.3
7	25°.5	7°.4	18°.9	0°.8

(*f*) Plot two curves showing the slope of temperature for each bar on the same sheet of squared paper, taking distances along the bar as abscissae and corresponding excesses of temperature as ordinates. These curves are represented in Fig. 73.

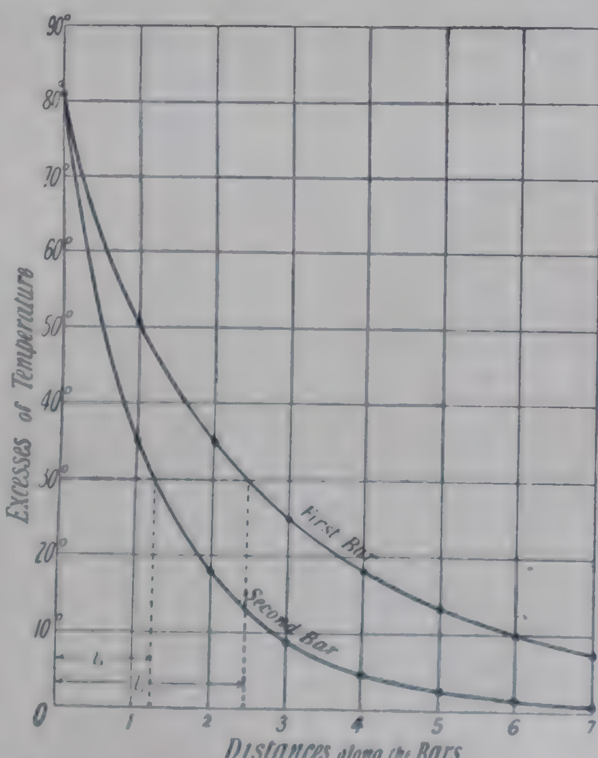

FIG. 73.—Curves showing the excesses of temperature at different points along two bars.

(ii.) **Reduction of the results obtained.** (*a*) If the excesses of temperature for the various points along the bar are denoted by $\theta_0, \theta_1, \theta_2, \ldots, \theta_7$, and $\theta_0', \theta_1', \theta_2', \ldots, \theta_7'$ respectively for the two bars, it may be shown that

$$\frac{\theta_0+\theta_2}{\theta_1}=\frac{\theta_1+\theta_3}{\theta_2}=\text{etc.},$$

is a constant quantity $=2n_1$ (say).

Also $$\frac{\theta_0'+\theta_2'}{\theta_1'}=\frac{\theta_1'+\theta_3'}{\theta_2'}=\text{etc.,}$$

is also a constant$=2n_2$ (say).

e.g. for the first bar the calculated values of $2n_1$ are 2.31, 2.14, 2.12, 2.11, 2.14, and 2.07 respectively;

for the second bar the values of $2n_2$ are 2.82, 2.46, 2.54 2.32, 2.50, and 2.46 respectively.

Verify the above from your results and calculate the average values of n_1 and n_2 for the two bars.

Hence calculate the ratio of the conductivities k_1 and k_2 for the bars by means of the formula

$$\frac{k_1}{k_2}=\left[\frac{\log(n_2+\sqrt{n_2^2-1})}{\log(n_1+\sqrt{n_1^2-1})}\right]^2$$

(*b*) Assuming that the ratio of the conductivities is given by

$$\frac{k_1}{k_2}=\frac{l_1^2}{l_2^2}$$

Where l_1 and l_2 are the corresponding points on the two rods at which the excess of temperature is the same, it is evident we can find the ratio of the conductivities from the curves obtained in (5) (Fig. 73).

Calculate by this method the ratio $\frac{k_1}{k_2}$, when the excess of temperature is (1) 30°, (2) 40°, (3) 50°.

NOTE.—The chief objection to the above method is that the thermometer holes introduce a discontinuity in the material which affects the flow of heat. The only method of reducing this defect is to make the holes as small as possible, care being taken to drill them to exactly the same depth. The temperature readings can be read fairly accurately with only one special thermometer by starting at the cold end of a bar and working up to the hot end, the thermometer holes having been previously filled up to the top with mercury. To avoid the use of mercury thermometers thermo-electric couples may be used consisting of iron and nickel wires about 32 B.W.G. or 34 B.W.G. soldered in small holes 1 mm. in depth which are drilled at opposite ends of the diameter of the rod. The holes are closer together near the source of heat, *i.e.* where the temperature slope is steepest.

85. Determination of the relative conductivities of thin layers of materials (Lees's and Chorlton's method).*

Apparatus.—The apparatus consists of a flat cylindrical box A (Fig. 74) 11.5 cms. diameter and about 5 cms. deep, through which steam can be passed. The bottom of the box is formed of a circular brass plate B, 1.2 cm. thick, in which a radial hole is bored to the centre. This vessel is supported on a circular plate C of the material under test, which in turn is supported on a brass disc, D, of exactly the same dimensions as the base of the steam box. The lower disc is suspended by three strings from the ring of a retort stand. A screened thermometer, placed horizontally under the apparatus, registers the temperature of the air ascending to the disc. The two surfaces of the discs in contact with the substance are electro-plated, while the under surface of B is polished so that

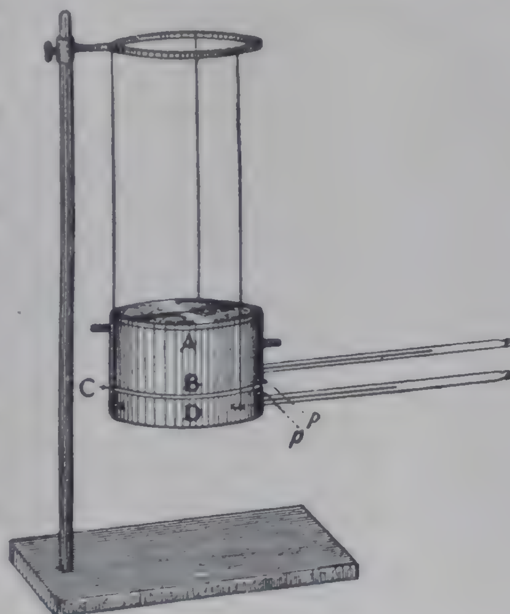

FIG. 74.—Apparatus for the determination of conductivities of thin discs of material (Lees's and Chorlton's method).

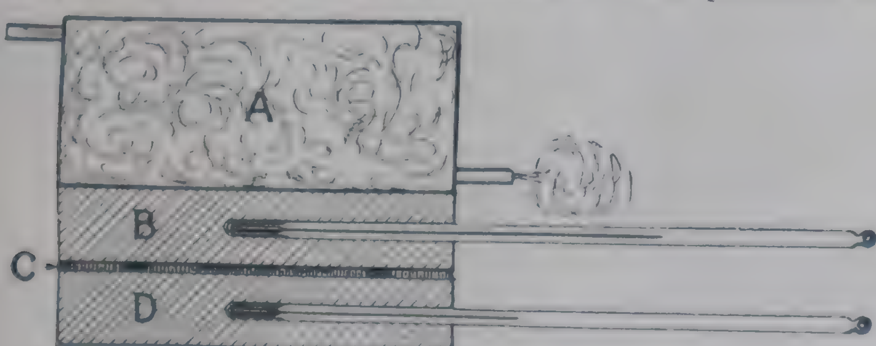

FIG. 75.—Arrangement of apparatus for the conductivity of a liquid.

the heat radiated may be constant. In most cases of powders and liquids the thickness of the layer of material may be made

* See *Philosophical Magazine*, June, 1896.

constant by placing on the lower plate three discs made from a microscope slide, and squeezing out any superfluous substance with the upper plate (Fig. 75). If the liquid is very mobile it is enclosed in a thin ebonite ring placed on the lower plate.

(*a*) Having placed a layer of material between the upper and lower plates, suspend the apparatus as in Fig. 74 and pass steam through A. Heat flows through the material to the lower brass plate, and when the steady stage is reached the loss of heat from the lower plate is equal to the heat received from the material under test.

(*b*) Read the thermometers in the upper and lower plates and note the temperature of the air.

Then if t_0° = temperature of air
t_1° = temperature of lower plate
t_2° = temperature of upper plate
x = thickness of the disc of material
k = conductivity of material.
s = area of each disc.

Loss of heat per second from lower plate to the air $= h(t_1 - t_0)$ where h is a constant depending on the external emissivity and on the dimensions of the plate.

Heat flowing through material per second $= k.s\,.\,\dfrac{t_2 - t_1}{x}$.

When the stationary stage of the experiment is reached

$$k.s\,.\,\frac{t_2 - t_1}{x} = h(t_1 - t_0)$$

or
$$k = \frac{h}{s}\,.\,x\,.\,\frac{t_1 - t_0}{t_2 - t_1};$$

i.e.
$$k \propto .\,x\,.\,\frac{t_1 - t_0}{t_2 - t_1}.$$

e.g. In the case of glass

$$t_1^\circ = 92^\circ.4, \quad t_2^\circ = 96^\circ.1, \quad t_0^\circ = 20^\circ.0, \quad x = 0.292 \text{ cm.}$$

$$\therefore\ k \text{ is } \propto \frac{72.4}{3.7} \times 0.292.$$
$$= \underline{8.79.}$$

(*c*) Determine the relative conductivities of silk, wool, flannel, glass, and asbestos in the above manner. The thickness x is

measured by noting the distances between three short metal pins in the lower plate and three corresponding pins in the upper plate before and after the material is interposed.

86. Conductivity of Gases.

The difficulty in the determination of the conductivity of a gas lies in the separation of the effects of conduction, convection, and radiation which are brought into play. It is found that the conductivity of a gas is independent of the pressure (except in the case of very low pressure) and as the effects of convection currents are inappreciable at low pressures it is evident that under fairly low pressures we have to deal only with the radiation and conduction.

Apparatus.—Copper flask, thermometer with spherical bulb, air pump, ice.

(*a*) Take a round-bottomed copper flask A (Fig. 76) and fill it with a two-holed rubber stopper. Through one hole pass a thermometer B having a somewhat large spherical bulb, and through the other hole push a stopcock C which is in connection with the exhaust pump.

(*b*) Exhaust the flask by means of an air pump until a pressure of about 5 cms. of mercury is reached. Then close the tap C and heat the whole of the apparatus to 100° C. and plunge it into a vessel containing a mixture of ice and water at 0° C. Note the time taken to cool from 80° C. to 70° C., 70° C. to 60° C. etc., down to 10° C. These velocities of cooling are due to both radiation and conduction.

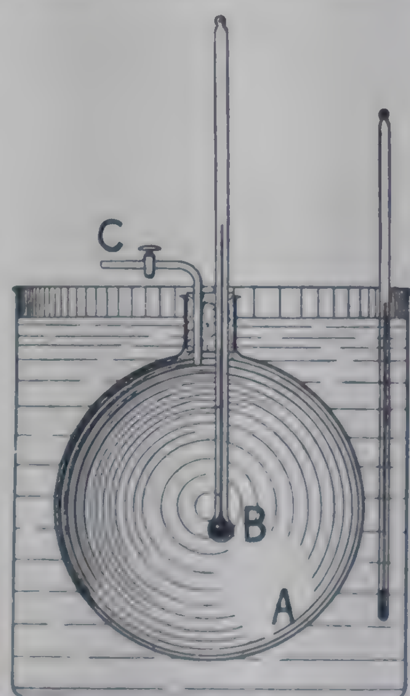

FIG. 76.—Apparatus to determine the conductivity of a gas.

(*c*) Now exhaust the flask to the best vacuum possible, again heat the flask to 100° C. and repeat the observations for the

velocities of cooling at the same temperatures as before. These results are due to radiation only. Subtract the numbers obtained in (*c*) from those in (*b*) and the difference gives the velocity of cooling due to conduction.

(*d*) Compare by this method the relative conductivities of air, oxygen and hydrogen at a pressure of 5 cms. of mercury, being careful to thoroughly dry the gases before placing them in the flask.

NOTE.—Instead of initially exhausting the sphere it may be connected to a larger sphere D (Fig. 77), which is already exhausted to the required pressure, and by opening the tap C momentarily the sphere A will be exhausted immediately, the pressure being noted on the manometer M. By this method only the thermometer need be heated to 100° and plunged into the sphere A, the pressure being reduced as above.

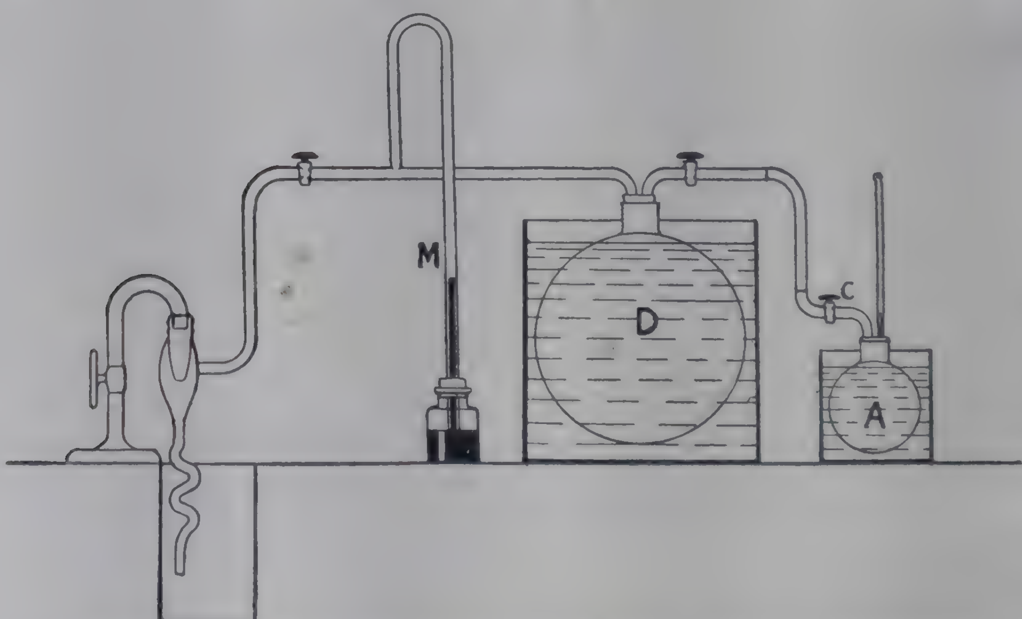

FIG. 77.—Arrangement for exhausting metal sphere, used in the experiment on the conductivity of gases.

ADDITIONAL NOTES ON CHAPTER XII.

(1) A number of interesting experiments on conduction, convection, and radiation are described in *Heat Shadows*, by W. Jamieson (Blackie & Son). A special kind of sensitive paper sold by W. B. Nicholson, 54 Hill Street, Glasgow, is used

in the experiments, and this paper possesses the property of turning bright green when heated, reverting to its original tint on cooling.

(2) *Prof. Searle's apparatus* for the measurement of thermal conductivity consists of a short copper bar about 20 cms. long and 2.5 cms. diameter. One end is heated by a steam coil, while the other is kept cool by a narrow copper tube wound spirally round that end of the rod. The temperature gradient is measured by means of two thermometers fixed about 10 cms. apart in the metal bar. When the thermal conditions have become steady, if $t_1°$ and $t_2°$ are the readings of the thermometers on the rod, and $t_3°$, $t_4°$ the temperatures of the outflowing and inflowing water, A = area of cross-section of rod, w = number of grams of water flowing through per second, d = distance between thermometers.

The rate of flow of heat $= \dfrac{KA(t_1 - t_2)}{d}$.

$$\left.\begin{array}{l}\text{Amount of heat per second}\\ \quad\text{carried away by water}\end{array}\right\} = w(t_3 - t_4).$$

Equating these two expressions, we have

$$K = \frac{wd(t_3 - t_4)}{A(t_1 - t_2)}.$$

(3) The testing of heat insulating materials for steam pipes may be carried out by a method suggested by C. R. Darling. A piece of pipe about 8″ long and 6″ diameter is coated with the given material to a thickness of $1\frac{1}{2}$″. A 32 C.P. incandescent lamp is placed inside as the source of heat, and a screened thermometer registers the inside temperature. An adjustable resistance in the lamp circuit enables the temperature to be kept constant, and by means of the ammeter and voltmeter readings the number of thermal units escaping per square foot of material per hour may be determined.

[*N.B.*—1 volt × 1 ampère = 0.24 calorie per second = 0.057 British thermal unit per minute.]

Additional Exercises.

1. Compare the conductivities of the given bars.
2. Compare the conductivities of water and glycerine by the disc method.

3. Find the relative conductivities of sand, salt, sawdust, and water.

4. Plot the conductivity curve for the given bars and determine the ratio of their conductivities for an excess of temperature of 10° C. above that of the surrounding air.

5. Blow steam against one end of a copper bar and plot against time the rise of temperature at a point 2 cms. distant from this end. (Int. Sci. Hons. Lond. 1899.)

6. Find the thermal conductivity of copper, given a rod of the material. (Int. B.Sc. Hons. Lond. 1908.)

7. Find the thermal conductivity of (*a*) a glass tube, (*b*) a copper bar, (*c*) indiarubber. (Ext. B.Sc. Pass Lond. 1908.)

8. Measure the conductivity of glass by a method of continuous flow. (Int. B.Sc. Pass Lond. 1909.)

9. Measure the heat conductivity of the copper bar supplied by Ångström's method of alternately heating and cooling one end of the bar. (Int. B.Sc. Hons. Lond. 1909.)

10. Compare the thermal conductivities of copper and iron. (Ext. B.Sc. Pass Lond. 1909.)

11. Determine the thermal conductivity of the metal bar, using the thermo-junctions to measure the temperature. (Ext. B.Sc. Hons. Lond. 1910.)

12. Determine the conductivity of a brass rod by the bar method, radiation and convection occurring from the exterior surface. (Int. B.Sc. Hons. Lond. 1910.)

CHAPTER XIII.

RADIATION.

87. Definition of Radiation.

Thermal radiation may be defined as the passing of heat from one point to another without heating any material medium. The radiant energy is transmitted by the hypothetical medium known as the *luminiferous ether*. In the case of an electric incandescent lamp the filament radiates heat through the vacuum in all directions and a thermometer placed near the lamp will quickly show a rise in temperature. If the thermometer bulb is covered with dead black paint (made by mixing lampblack with shellac varnish) the rise in temperature is increased. A similar result is obtained by covering the outside of the lamp with the black paint and leaving the thermometer bulb uncovered.

88. Differential air thermometer.

Apparatus.—A differential air thermometer (Fig. 78) made by fastening together two glass bulbs by a tube bent twice at right angles, and in which some coloured liquid is placed. The bulbs may be covered with dead black paint so as to absorb the radiations quickly.

(*a*) Notice that when one bulb is at a higher temperature than the other the level of the liquid in the **U**-tube is altered, the liquid approaching the bulb which is at the lower temperature.

(*b*) Place two concave mirrors facing each other and about 3 feet apart. Place a red-hot metal ball at the focus of one mirror, move the air thermometer about near the other mirror

and notice that the heating effect is greatest at the focus, showing that radiant heat obeys the same laws as light.

(*c*) Place the air thermometer about a foot away from a gas jet and note the reading where various substances are interposed, *e.g.* sheets of clear glass, mica, rock-salt, smoked glass, etc. This Expt. will show which substance transmits radiant heat the best.

(*d*) Take a hollow metal cube and cover three of the vertical faces with lampblack, paper, and white paint respectively, while the fourth face is left uncovered and simply polished. Such a cube is known as a Leslie's tube. Fill the cube with boiling water and quickly bring the air thermometer near each of the faces of the cube in turn. Note the reading in each case and arrange the surfaces in order of their radiating powers.

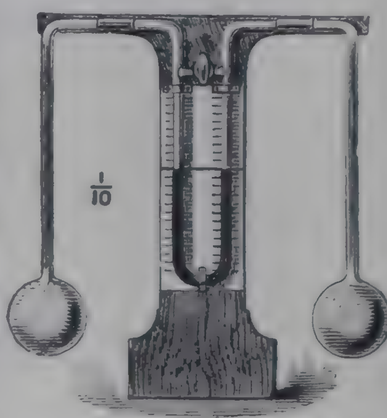

FIG. 78.—Differential air thermometer.

In general it may be stated that where radiant heat falls on any surface

1. Part of the heat is reflected according to the same laws as light.

2. Part of the heat is diffused or irregularly reflected by the surface.

3. Part of the heat is transmitted through the substance.

4. Part of the heat is absorbed.

89. Comparison of emissive powers of surfaces.

Apparatus.—Leslie cube, a thermopile and galvanometer.

The thermopile (Figs. 79 and 80) consists of a number of antimony-bismuth thermo-electric couples insulated from each other and with their ends soldered together alternately. In Fig. 79 the bismuth bars are shaded and the antimony bars are left clear. The couples are arranged in a rectangular block, and the two free ends connected to two terminals (Fig. 80). If one face of the thermopile is kept at a constant temperature and the other face exposed to a source of heat an electric current is

generated, which is quantitatively measured by using a galvanometer * with a lamp and scale.

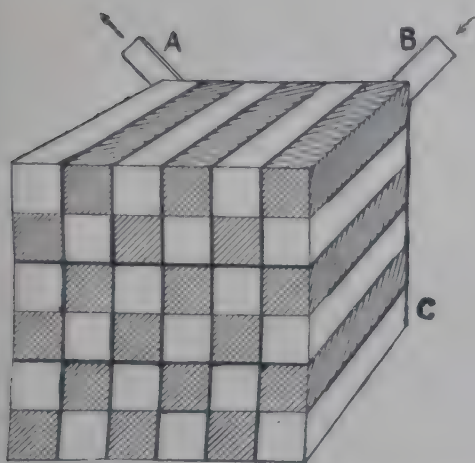

FIG. 79.—Arrangement of metal bars in the thermopile.

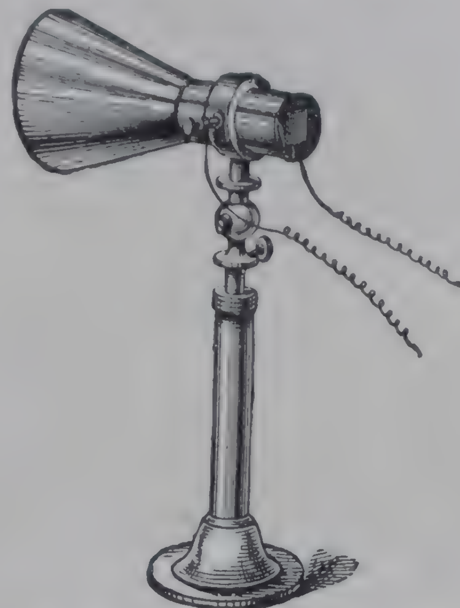

FIG. 80.—Thermopile ready for use.

The exposed faces of the thermopile are covered with lampblack and fitted with brass caps when not in use.

(*a*) Fill the Leslie cube A (Fig. 81) with water and heat the water to boiling point. Place the cube in position on the stand, and in front of it place the metal screen B and arrange the

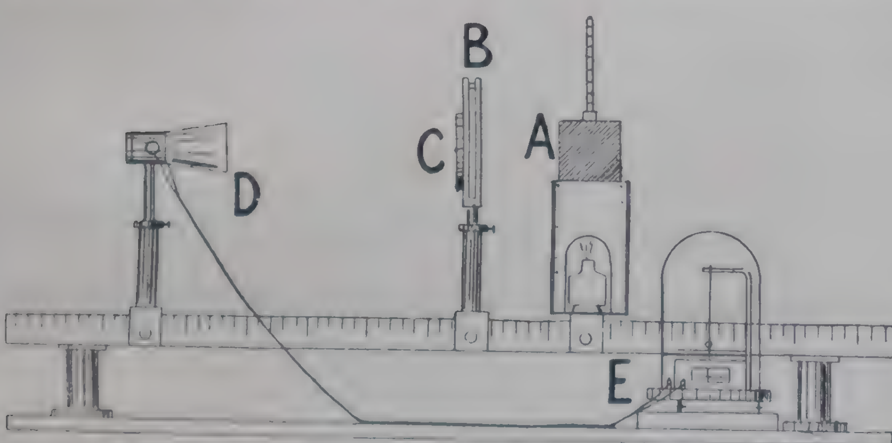

FIG. 81.—Apparatus to determine the emissive powers of surfaces.

* A reflecting astatic galvanometer, such as the d'Arsonval pattern, having a constant of about 10^{-8}, will be found to give accurate results.

diaphragm C so as to give a suitable deflection. Then turn the diaphragm so as to shut off the radiations.

(*b*) Place the thermopile D about 2 feet from the screen and connect it with 'twin' wire to the galvanometer E. Adjust the spot of light till it points to the zero mark.

(*c*) Turn each face of the Leslie cube in front of the diaphragm and allow the radiation to fall on the thermopile (Fig. 82). Note the galvanometer deflection in each case. Note the temperature of the water in the cube. The emissive power will be proportional to the deflection.

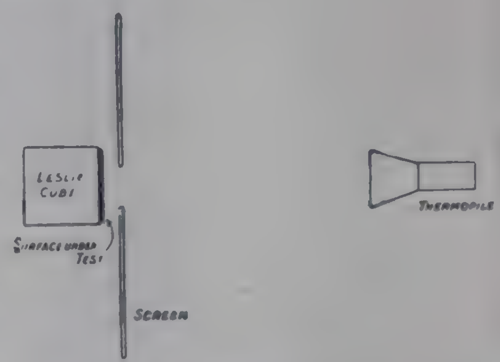

FIG. 82.—Arrangement of apparatus for emissive powers.

Surface.	Deflection.	Percentage.
Lampblack, - -		100.
White paint, - -		
Paper, - - -		
Polished brass, -		

90. Comparison of reflecting powers of surfaces.

The **reflecting power** of a surface is the ratio of the heat reflected at a given angle to the total heat incident on the surface.

Apparatus.—Source of heat, thermopile, galvanometer.

The source of heat may be :—

(1) A Leslie cube, which is filled with water to a fairly constant level, placed on a metal support, and heated by means of a spirit lamp.

(2) An Argand lamp, with a screen and slit similar to that used in photometric work.

(3) An incandescent lamp covered on the outside with a layer of black paint.

(4) A Locatelli lamp, which is practically a spirit lamp fitted with a reflector.

(5) A platinum spiral, heated by means of an electric current.

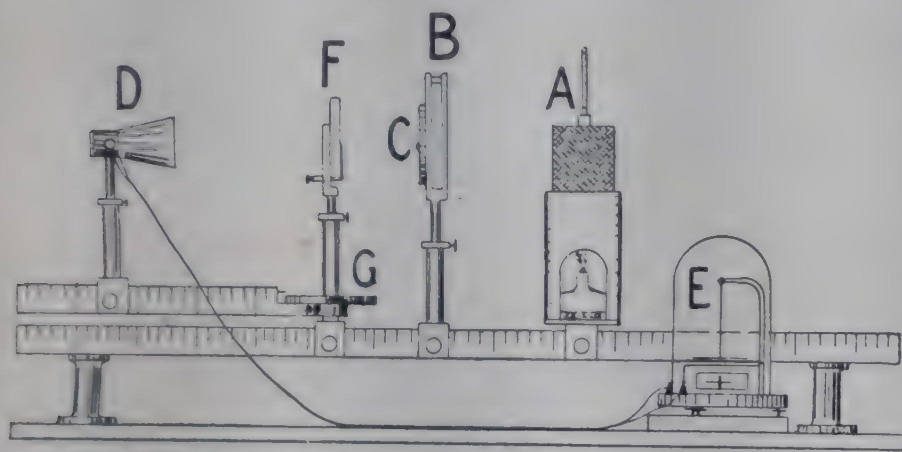

FIG. 83.—Apparatus to determine the reflecting powers of surfaces.

(*a*) Arrange the apparatus as in Fig. 83. A is a Leslie cube, or other source of heat; B, screen; C, diaphragm; D, thermopile; E, galvanometer; F, surface under test.

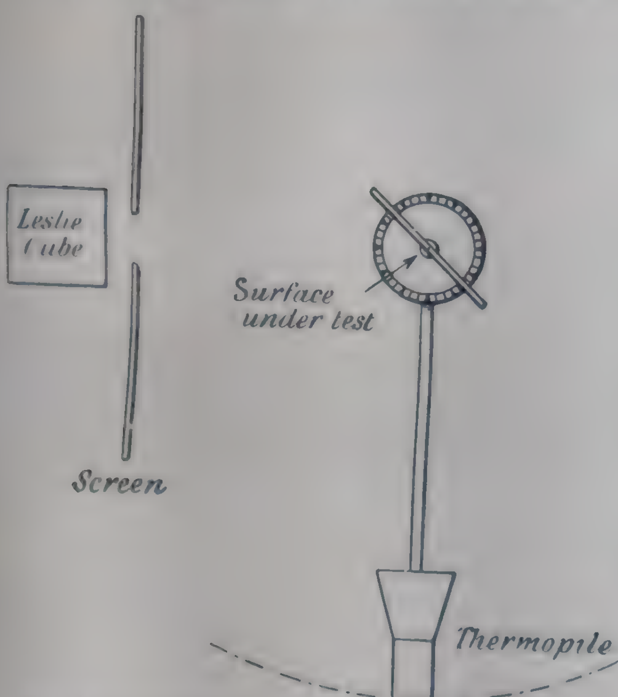

FIG. 84.—Arrangement of apparatus for reflective powers.

The surface is placed at the centre of a circular graduated table and the thermopile is placed on a radial arm so as to catch the reflection at any angle.

(*b*) Take away the surface and allow the heat from the lamp-black face of the Leslie cube to come directly on the thermopile. Note the galvanometer reading d_1.

(*c*) Place in position the surface to be tested, and arrange it so that it is inclined at 45° with the incident rays (Fig. 84). Again note the galvanometer reading d_2.

Then the reflecting power of the surface $=\frac{a_2}{d_1}$.

(*d*) Test in this way the reflecting power of lampblack, tinfoil and paper.

Surface.	d_1.	d_2.	Reflecting Power $\frac{d_2}{d_1}$.	Percentage.
Tinfoil.				100

91. Comparison of diffusive powers of different surfaces.

Apparatus.—As in Expt. 90. Thin sheets of copper are also required both sides of which are coated with the substance to be tested. The metal sheets are placed in wooden frames so as to receive the rays of heat from the source.

(*a*) Arrange the apparatus as in the previous Expt., except that the copper sheet replaces the reflecting surface. Place one of the sheets in position parallel to the lampblack face of the cube.

First place the thermopile in the position α (Fig. 85), and note the deflection of the galvanometer. The reading is proportional to the sum of the heat radiated and diffused from the given surface. Call this deflection d_1. Now place the thermopile in the position β, making the same angle with the surface, but on the other side of it.

The deflection d_2 is proportional to the heat radiated only.

Then $(d_1 - d_2)$ is proportional to the heat diffused by the surface under test.

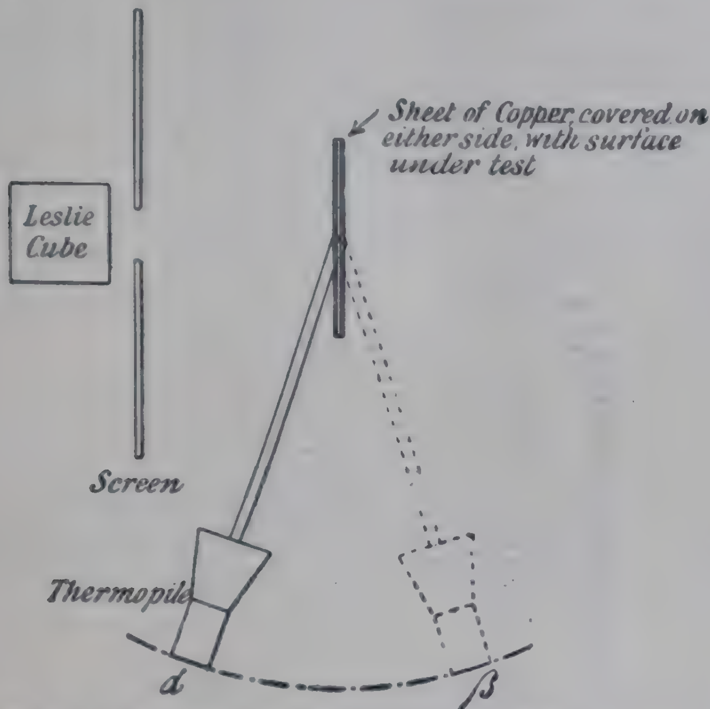

FIG. 85.—Arrangement of apparatus for diffusive powers.

(*b*) Test by this method lampblack, tinfoil, white paper, white lead, and taking the diffusive power of lampblack as 100 per cent. calculate the diffusive power of the other surfaces.

92. Comparison of powers of transmission (diathermancy powers).

The **comparative diathermancy** of a substance is the ratio of the amount of radiant heat transmitted to the amount of heat falling on the surface of the substance.

Apparatus.—As in Expt. 90.

(*a*) Arrange the apparatus as in Fig. 86.*

(*b*) Test the diathermancy of equal thicknesses of glass, mica, rock salt, calcspar, water, glycerine.

For liquids the diathermancy of the containing vessel must be subtracted from that of the liquid and vessel together. A circular glass microscope cell should be used for the purpose.

* As a source of heat for this experiment a variation may be made by using a spiral of platinum wire heated to incandescence or a Locatelli oil lamp, the flame of which is kept constant by keeping the oil at the same level.

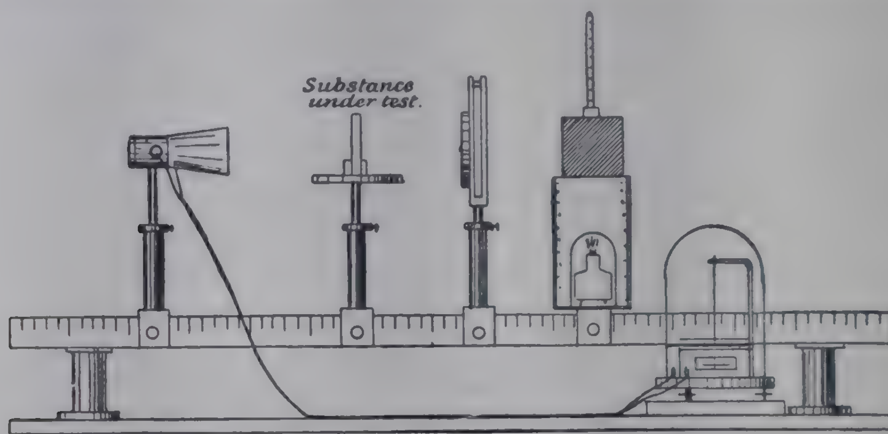

FIG. 86.—Apparatus for the determination of diathermancy powers.

Let d_1 = galvanometer deflection with substance present.

d_2 = deflection without substance, *i.e.* proportional to total incident heat.

Then, diathermancy $= \frac{d_1}{d_2}$.

93. Comparison of absorptive powers of different surfaces.

Apparatus.—As in Expt. 90.

(*a*) Place the surface under test on the front of a piece of copper foil which is backed with a coating of lampblack.

Place the copper foil close up to the thermopile after removing the brass hood. Set up the apparatus as in Fig. 87.

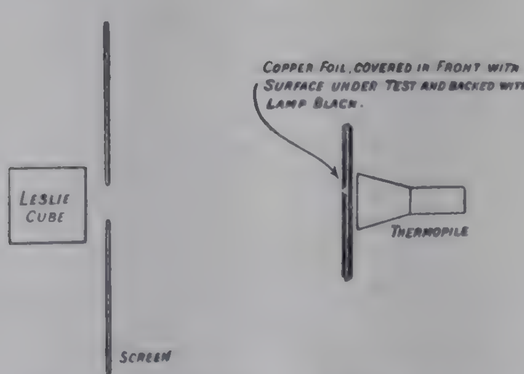

FIG. 87.—Arrangement of apparatus for the absorptive powers of different surfaces.

Since the lampblack side of the foil is next to the thermopile, in each case the absorbing power of the surface will be proportional to the deflection of the galvanometer.

(*b*) Test the absorbing power of lampblack, tinfoil, paper, and shellac, representing lampblack as 100 per cent.

(*c*) Repeat the experiment using as the source of heat (1) a glowing platinum spiral, (2) an Argand burner.

94. Experiments on cooling.

If a body has a different temperature from that of its surroundings it will gain or lose heat by radiation, conduction and convection.

Apparatus.—These different effects may be qualitatively illustrated by using the same apparatus as in Expt. 86.

(*a*) Heat the thermometer to any temperature and leave it to cool inside the copper vessel maintained at a constant temperature by placing it in cold water. Prove that the rate of cooling is determined by

(1) The emissivity of the surface of the bulb.
(2) The temperature of the enclosure.
(3) The temperature of the thermometer bulb.
(4) The pressure and nature of the enclosed gas.

95. Comparison of emissivities of different surfaces.

The **emissivity** of a surface may be defined as the quantity of heat emitted normally from unit area in unit time when its excess of temperature is 1° C. above that of the enclosure.

To compare different surfaces, the average rates of cooling of the thermometer bulb at the same temperatures are determined, and the emissive powers of the surfaces will be proportional to their respective rates of cooling.

Apparatus.—Copper sphere, thermometer with spherical bulb, ice, lampblack, tinfoil.

(*a*) Fix the copper sphere in a vessel containing cold water at a constant temperature. This can be obtained by using water at the temperature of the room and keeping the temperature constant by the addition of pieces of ice. Push the thermometer through the stopper so that the bulb will be at the centre of the sphere. Take the stopper and thermometer and quickly heat the bulb of the latter up to 100° C. by holding it above the flame of a Bunsen burner. Quickly replace the stopper in the enclosure. Take time readings of the temperature of the bulb

for every 10° C. fall in temperature beginning at 100° C. and continuing the observation until the temperature falls to that of the enclosure. Note the temperature of the enclosure.

(*b*) Repeat the above experiment with the thermometer bulb covered with tinfoil and lampblack respectively.

(*c*) Prove that the average rate of cooling at the intermediate temperatures, *i.e.* 95°, 85° C., etc., is inversely proportional to the time of fall in seconds. The numbers proportional to the average rate of cooling therefore represent the relative emissive powers for the different surfaces.

Enter each set of results as follows:

Temperature of enclosure $(\theta_0)=$

Nature of surface –

Temperature of bulb θ.	Excess of temperature $\theta-\theta_0$.	Time of cooling (t).	Emissivity $\propto \frac{1}{t}$.
100° 90° etc.			

(*d*) Repeat the experiments with the uncovered bulb when the excess of temperature is 10°, 8°, 6°, 4°, 2°, and show that with a small excess of temperature the rate of cooling $\left(\frac{1}{t}\right)$ is proportional to the excess of temperature $(\theta-\theta_0)$.

96. Determination of the influence of pressure on the rate of cooling.

Apparatus.—Thermometer with bulb uncovered, copper sphere. The sphere is fitted with a glass tube for exhausting the air inside. The pressure is reduced by a Bunsen filter-pump in connection with a mercury manometer. (See Fig. 77.)

(*a*) The thermometer bulb having been heated to 100° C. and quickly replaced in the enclosure the pressure is reduced to about 720 mms. The rate of cooling is now determined for a known excess of temperature, *e.g.* allow the bulb to cool from 50° to 40° C.

(*b*) Repeat the above experiment with the same excess of temperature above that of the enclosure but with pressures of approximately 360, 180, and 90 mms. respectively.

(*c*) Show from your results that if r_1, r_2, r_3, and r_4 are the rates of cooling at the pressures, p_1, p_2, p_3, and p_4 the following relation holds

$$\frac{\log \frac{r_1}{r_2}}{\log \frac{p_1}{p_2}} = \frac{\log \frac{r_2}{r_3}}{\log \frac{p_2}{p_3}} = \text{etc.} = \text{constant.}$$

97. Newton's law of cooling.

It has been seen from the previous experiments on cooling that a body at a different temperature from that of its enclosure will gain or lose heat by radiation, conduction, and convection. The following experiments will illustrate the laws on which this change of heat depends, and will also show the importance of the cooling correction in accurate calorimetric observations.

Apparatus.—Calorimeter placed in a cylindrical enclosure with a water jacket round it. Thermometer reading to 30° by 0°.1, thermometer reading to 100°.

(i.) **To observe the effects of convection currents on the temperature of the calorimeter.**

(*a*) Fill the calorimeter with water up to a certain mark and place it unprotected on the bench. The water being at a temperature of about 23° C. place the thermometer in the calorimeter and take readings every half minute, keeping the water well stirred.

Perform the experiment :

(*a*) When the calorimeter is unprotected.

(*b*) When the calorimeter is protected by the enclosure.

Enter results thus :

(a) Calorimeter unprotected.

Time.	Temperature.	Time.	Temperature.	Fall of temperature in 3 minutes.
h. m.		m.		
3 5	24°.07	8	23°.56	0°.51
5.5	23°.95	8.5	23°.55	0°.40
6	23°.85	9	23°.40	0°.45
6.5	23°.80	9.5	23°.33	0°.47
7	23°.70	10	23°.28	0°.42
7.5	23°.63	10.5	23°.20	0°.43
				2°.68

Average fall in 3 mins.

$$=\frac{2.68}{6}=0°.447,$$

Average fall in 1 min.

$$=\frac{0.447}{3}=0°.149,$$

Average temperature of calorimeter

$$=23°.61,$$

and similarly for (*b*) having the same amount of water at the same temperature.

FIG. 88.—Calorimeter an enclosure to show coolin effects.

(ii.) **To observe the effects of conduction and radiation.**—(*a*) In this case the calorimeter is placed in an enclosure (Fig. 88) having a double wall to it and the enclosure is filled with water at the temperature of the room. A thermometer is placed in the calorimeter and another in the enclosure.

(*b*) Fill the calorimeter up to the same mark with water a 50° C. and take the temperature of it as in (i.). Read the tem

perature of the enclosure before and after the experiment. Record thus:

Time.	Temperature.	Time.	Temperature.	Fall of temperature in 3 minutes.
h. m.		m.		
3 30	45°.0	33	43°.0	2°.0
30.5	44°.7	33.5	42°.7	2°.0
31	44°.3	34	42°.4	1°.9
31.5	44°.0	34.5	42°.1	1°.9
32	43°.7	35	41°.8	1°.9
32.5	43°.3	35.5	41°.6	1°.7
				11°.4

Average fall of temperature in 3 mins. = 1°.9,
Average fall of temperature in 1 min. = 0°.63,
Average temperature of calorimeter = 43°.22,

$$\text{Temperature of enclosure}\begin{cases}15^\circ.2.\\15^\circ.8.\end{cases}$$

(*c*) Repeat the experiment for water at 40°, 30°, and 20°.

(*d*) From the results determine (R) the ratio of the rate of cooling to the difference in temperature of calorimeter and enclosure thus:

Mean temperature of calorimeter.	Mean temperature of enclosure.	Difference.	Rate of cooling.	R
43°.22	15°.5	27°.72	0.63	0.0227
36°.23	15°.7	20°.53	0.43	0.0209
26°.65	15°.4	11°.25	0.20	0.0180
19°.80	15°.87	3°.93	0.072	0.0182

(*e*) Plot the results on a curve taking rates of cooling as ordinates and difference of temperature as abscissae.

When the difference of temperature of calorimeter and enclosure is small the rate of cooling is proportional to the difference in temperature and the curve is a straight line curve. This is called *Newton's Law of Cooling.*

(*e*) Measure the diameter of the calorimeter and the deptl of the water and thus find the area of the radiating surface From this calculate the loss of heat (E) per second from 1 sq. cm of surface, when the excess of temperature is 1° C. Find als the mass of water in the calorimeter so as to reduce the resul to gram-degrees. Thus :

Diameter of calorimeter = 6.5 cms.

Area of radiating surface $= 2\pi r(h+r) = 168.5$ sq. cms.

if h = depth of water in calorimeter.

r = radius of calorimeter.

Weight of water in calorimeter = 152 grams.

$$\therefore \text{ E (1)} = \frac{.63}{60} \times \frac{1}{27.72} \times \frac{152}{168.5} = 0.00034$$

$$(2) = \frac{.43}{60} \times \frac{1}{20.53} \times \frac{152}{168.5} = 0.00032$$

$$(3) = \frac{.20}{60} \times \frac{1}{11.25} \times \frac{152}{168.5} = 0.00026$$

$$(4) = \frac{.072}{60} \times \frac{1}{3.93} \times \frac{152}{168.5} = 0.00016$$

It will be noticed that E is the emissivity of the surface of the calorimeter.

Additional Notes on Chapter XIII.

(1) A series of interesting preliminary experiments on radiatior are given in *Heat Shadows*, by W. Jamieson (Blackie & Son) a special kind of heat sensitised paper being used.

(2) *Looser's double thermoscope* (Griffin & Son) is an attemp to demonstrate the laws of heat quantitatively. Instead of the usual glass bulbs there are receivers of various shapes (hemi-spherical, cylindrical, etc.), each receiver being connected by a water gauge. The comparison of specific heats, the deter-mination of latent heats and thermal conductivities, the production of cold by evaporation, etc., may be shown in ar efficient manner with the apparatus.

(3) The *Ruben's linear thermopile* is much smaller than the Melloni type, and has fine iron-constantin thermo-couples, thus reducing the thermal capacity of the instrument. Every alternate

junction lies on a central vertical line, while the others lie half of them to the right, and half to the left. The zero is very stable and the instrument rapidly assumes a steady condition although the E.M.F. is about half that of bismuth-antimony couples.

(4) *Boys' radio-micrometer* consists of a thermal junction fastened to a copper disc, on which the radiant heat falls, and the disc is suspended between the poles of a powerful electro-magnet. The induced current circulating in the junction circuit causes the disc to rotate, and by means of an attached mirror a spot of light can be focussed to a scale (see Edser's *Heat*, page 410). For a description of *Langley's bolometer*, see Edser's *Heat*, page 404.

Additional Exercises.

1. Construct a simple air thermometer and use it to test the relative radiating powers of (*a*) bright tin, (*b*) paper, (*c*) red paint, (*d*) lampblack.

2. Plot a cooling curve for a thermometer inside an enclosure surrounded by ice and water at 0° C.

3. Calculate the water equivalent of the given thermometer bulb and use it to determine the emissivity of the bulb at a temperature of 30° C.

4. Compare the ratio of cooling for a bulb in an enclosure containing (*a*) dry air, (*b*) oxygen.

5. Plot the curve of cooling for a given body and determine the amount of heat lost by it per second at 50° C.
(Int. Sci. Hons. Lond. 1890.)

6. Given a thermopile and galvanometer compare the diathermancy of the given substances to given sources of radiation.
(B.Sc. Pass Lond. 1892.)

7. Compare the rate of radiation from the different sides of a Leslie cube by means of the thermopile and galvanometer.
(B.Sc. Pass Lond. 1893.)

8. Draw a curve showing the relation between the radiation and temperature by means of a Leslie cube and thermopile.
(B.Sc. Hons. Lond. 1893.)

9. Test Newton's law of cooling by means of the given apparatus.
(B.Sc. Hons. Lond. 1893.)

10. Test the law of radiation from a Leslie cube up to an excess of 70° by means of a thermopile.

(B.Sc. Hons. Lond. 1897.)

11. Compare the radiating powers of two given surfaces by means of a thermopile. (B.Sc. Pass Lond. 1897.)

12. Plot a curve showing the radiation from a lampblacked cube filled with boiling water to a thermopile at different distances from it. (Int. Sci. Hons. Lond. 1899.)

13. Investigate by a thermopile the relation between the amount of heat it receives from a given hot body and the distance of that hot body from the thermopile.

(Int. Sci. Hons. Lond. 1899.)

14. Compare with the thermopile the relative amounts of radiation received through a pair of Nicol prisms and verify the law as to its amount for different angles between their principal planes. (B.Sc. Hons. Lond. 1900.)

15. Compare the thermal radiations from the given faces of the hot body. (Int. B.Sc. Pass Lond. 1907.)

16. Plot a curve showing how the rate of cooling over a certain range, of a thermometer mounted in an enclosure, depends on the pressure of the surrounding air.

(Ext. B.Sc. Pass Lond. 1909.)

17. Test Newton's Law of cooling for a calorimeter at 70°, 50°, and 30° C. (Ext. B.Sc. Hons. Lond. Chemistry, 1911.)

18. Determine the conductivity of glass by measuring the rate at which heat passes through the walls of a tube, one surface of which is exposed to steam at 100° C. (Board of Education, 1906.)

CHAPTER XIV.

THERMODYNAMICS.

98. Preliminary experiments.

Apparatus.—Copper sphere, thermometer, bicycle pump, ice, manganin wire, battery, electromagnet, fusible alloy.

(*a*) Take the copper sphere used in Expt. 86 and fit a bicycle valve through the rubber stopper. Place the thermometer inside. Now work the pump for a few minutes and note that the temperature is raised by the incoming air.

(*b*) Take a piece of brass rod about 0.5 inch diameter and 1 inch in length and having in the centre a hole drilled to a depth of 0.5 inch and with a diameter of 0.25 inch. Now with a drill which easily fits the hole bore the tube for about a minute, then fill the hole with mercury and take the temperature of the piece of brass. Notice that the boring tool is also heated.

(*c*) Rub two flat pieces of ice together holding them with large pieces of cotton-wool or other non-conducting material. Notice that the ice is melting at the surface of contact. Collect some of the water thus formed and quickly take the temperature, which will be found to be above freezing point.

In the above experiments there is a certain amount of mechanical energy expended and in each case heat is produced.

(*d*) Take a coil of manganin wire and connect it for a short time to the terminals of an electric battery. The wire becomes heated because the electric energy passing through the wire is being partly dissipated in the form of heat.

(*e*) Fix a brass tube closed at one end to the spindle of a

whirling table (Fig. 89). Fill the tube half full of a fusible alloy, *e.g.* Wood's alloy, and place it so that it can be revolved between the poles of a strong electromagnet.

First revolve the brass tube without the current being on in the electromagnet. Note that the temperature is practically the same before and after the experiment.

Connect up the current to the magnet and notice that it requires more effort to revolve the tube and also that the

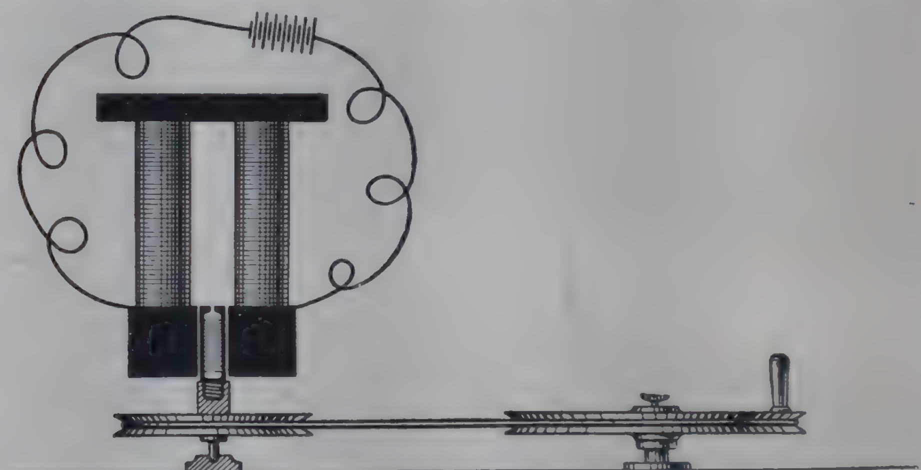

FIG. 89.—Apparatus to show the transformation of energy.

temperature rises so as to cause the alloy to melt. Part of the energy required to revolve the tube in the magnetic field is expended in creating electric currents in the brass tube and the contained alloy, and these currents are in turn changed into heat.

(*f*) Take a compression syringe and fit a thermo-couple into the interior; connect the thermo-couple to a galvanometer and work the syringe. The heat produced by the compression of air in the syringe will cause the galvanometer to show a deflection.

It is found that when mechanical energy is converted into heat or *vice versâ* the ratio of the mechanical energy to the heat is constant.

The amount of energy corresponding to unit quantity of heat is known as Joule's equivalent (J.).

99. Rough determination of Joule's equivalent.

Apparatus.—Cardboard cylinder, leaden shot, thermometer.

(*a*) Take a card-board tube about a metre in length and 5 cms. in diameter. Fit the two ends with tightly fitting corks and place inside the tube about a pound of leaden shot. Note the temperature of the shot ($t_1°$).

(*b*) Now place the tube vertical and quickly give it half a turn so that the other end comes uppermost. Repeat this 100 times, quickly take out the pellets, and note the temperature ($t_2°$).

The kinetic energy of the pellets acquired by falling is suddenly transformed into heat on reaching the bottom of the tube.

If m=mass of pellets.
h=height from top of tube to level of pellets.
s=specific heat of lead.
g=acceleration due to gravity=981 cm./per sec.^{2}

Then the kinetic energy of the shot = 100 mgh ergs.

The amount of heat produced = $ms(t_2 - t_1)$ calories.

$$\therefore \text{ the value of J} = \frac{\text{energy dissipated}}{\text{heat produced}}$$

$$= \frac{100mgh}{ms(t_2 - t_1)} = \frac{100gh}{s(t_2 - t_1)},$$

showing that the result is independent of the mass of the falling body.

100. Determination of the value of 'J' by the friction method.

This method depends on the fact that if a conical vessel containing a liquid is surrounded by a tight-fitting revolving cone, then the energy produced by the friction of the vessels will be spent in raising the temperature of the vessels themselves and also that of the liquid in the inner one.

Apparatus.—Puluj's apparatus (Fig. 90), which consists of two steel cones A, A, the outer one being screwed to a revolving shaft, while the inner one, filled with mercury, is free to move according to the amount of friction between the two. To the inner cone is fixed a wooden pointer B, the short end of which

moves over a metal scale S, while the longer end is connected to a string bearing a weight W and passing over the pulley D.

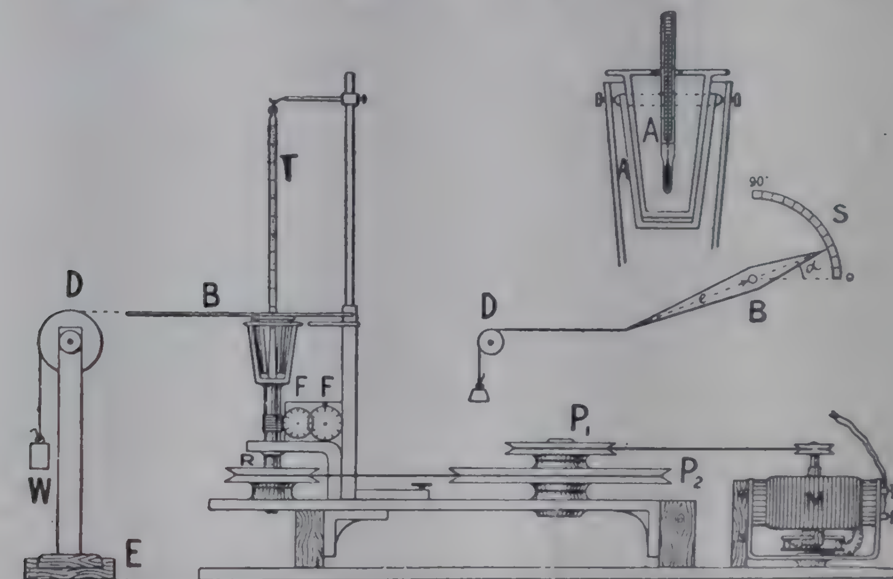

FIG. 90.—Puluj's apparatus for the determination of the mechanical equivalent of heat.

Instead of using a weight the string may be passed *under* the pulley and fastened to a delicate spring balance graduated to read 0.5 gram (Fig. 91). The pulley can move parallel to itself by means of the support moving in a slot cut in the base E. The thermometer T serves to register the temperature of the inner cone.

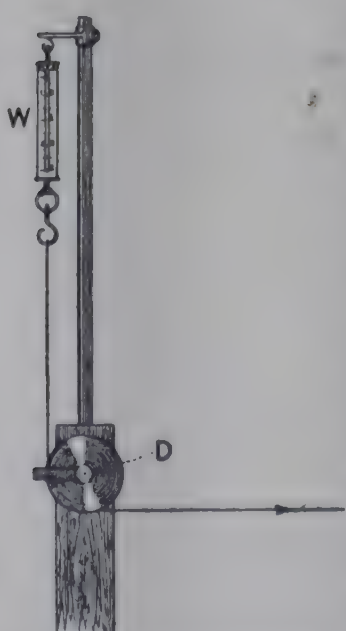

FIG. 91.—Arrangement for spring balance attachment in Puluj's apparatus.

The revolution dials FF register the number of revolutions of the outer cone; the apparatus is driven by a $\frac{1}{12}$ H.P. electric motor M coupled to a wooden pulley P_1, while a metal counter pulley P_2 is connected to the spindle R. With six secondary cells on the motor a speed of 1000 revolutions per minute is obtained, and the quickness of the experiment materially reduces the cooling corrections.

(*a*) Place a weight W on the string over the pulley (Fig. 90)

and move the pulley D so that the string and pointer are in a line with the zero mark on the scale S. The weight W should produce a deflection of about 30° when the apparatus is at work.

(*b*) Note the temperature $t_1°$ and also the readings on the speed dials.

(*c*) Switch on the current with a two-way key, and at the same instant note the time of starting.

(*d*) When the temperature has risen about 10° C. note the deflection on the scale S, and wait until the next half minute then switch off the current, noting the exact time.

(*e*) Take the temperature of the inner cone and then allow it to cool for one half the time taken for the experiment. Note the fall in temperature, and add this to the first reading in order to get the exact temperature allowing for cooling (t_2). A more accurate method of determining the cooling correction is described in Expt. 32. Even when great care is taken the cooling effect will be found to be underestimated, because the outer cone will naturally cool at a greater rate when it is in motion.

(*f*) Read the speed dials again and thus find the number of revolutions (n).

(*g*) Measuring the distance of the longer end of the wooden pointer to the centre of the cones (l).

(*h*) Find the weight of the mercury and cones as follows: Unscrew the wooden arm from the inner cone, and weigh the two cones and mercury all together. Pour the mercury into a beaker and weigh the cones by themselves (m_2). The difference gives the weight of mercury (m_1). Summing up we have:

If n = number of revolutions.
W = weight in grams.
α = angle of rotation on scale S.
l = distance from outer end of wooden cone to centre,

then work done by friction of cones $= 2\pi n W l \sin\alpha \times 981$ ergs.

If m_1 = mass of mercury.
m_2 = mass of 2 steel cones.
s_1 = specific heat of mercury.
s_2 = specific heat of steel.
$(t_2 - t_1)$ = rise in temperature of mercury and cones,

then heat developed $= (m_1 s_1 + m_2 s_2)(t_2 - t_1)$ calories.

If J = amount of work required to raise 1 gram of water through 1° C,

work required to develop the above amount of heat

$$= J(m_1s_1 + m_2s_2)(t_2 - t_1);$$

$$\therefore\ J(m_1s_1 + m_2s_2)(t_2 - t_1) = 2\pi n W l \sin\alpha \times 981;$$

$$\therefore\ J = \frac{2\pi n W l \sin\alpha \times 981}{(m_1s_1 + m_2s_2)(t_2 - t_1)}.$$

Take $s_1 = 0.112$,

$s_2 = 0.033$,

and obtain $\sin\alpha$ from Tables, p. 210.

E.g.

$W = 50$ grams.

$\alpha = 27°$.

$l = 29.4$ cms.

$m_1 = 182$ grams.

$m_2 = 123$ grams.

$n = 3082 - 589 = 2493$.

$t_1 = 16°.7$.

$t_2 = 26°.1 + 0°.5 = 26°.6$.

$\sin\alpha = 0.454$.

Time of experiment $= 2\frac{1}{2}$ minutes.

$\therefore$ J (calculated) $= 4.2 \times 10^7$ in C.G.S. units.

Repeat the above experiment using a spring balance (Fig. 91) to indicate the tension, and arranging the pull so as to make $\alpha = 90°$.

NOTE.—To avoid unscrewing the outer cone and disturbing the adjustment its weight can be determined once for all, consequently it will only be necessary to weigh the inner cone and the mercury.

101. Determination of the value of Joule's equivalent 'J' by the electrical method.

To determine the heat equivalent of a definite amount of electric energy we require a means of measuring the potential difference and the strength of the current used, and at the same time we must determine the heat evolved by placing

the wire through which the current passes into a calorimeter containing water.

Apparatus.—The apparatus used (Fig. 92) is that designed by Prof. Ayrton, and consists of:

(i.) A strip of manganin $\frac{1}{4}$ inch wide, 0.003 inch thick, and about 10 ft. long, wound so as to form the top and bottom of a hollow cylinder, the coils being insulated by fastening them on an ebonite frame and coating them with varnish.*

(ii.) A thin glass cylinder just large enough to hold the manganin coil, and into which about 2 litres of water is placed. A scratch mark on the side of the vessel gives the depth to which it must be filled so as to hold the required volume.

(iii.) The ends of the strip are soldered to thick copper leads which are connected with a source of current, *e.g.* a number of secondary cells, so as to give a current of 25—30 ampères with a pressure of 7—10 volts.

(iv.) An ammeter and switch are arranged in series with the coil, while a voltmeter is placed across the ends of the coil and serves to measure the potential difference.

(v.) A delicate thermometer reading to 0°.01 C. registers the temperature of the water in the glass calorimeter. The cooling correction of the water may be disregarded if the initial temperature of the water is just as much *below* the temperature of the room as the final temperature is *above* the room temperature.

The rise of temperature should be about 8°, so that the initial temperature of the water should be cooled (using ice if necessary) so as to be 4° below the temperature of the room.

(*a*) Arrange the apparatus as shown in Fig. 92.

C = manganin coil.	T = thermometer.
V = voltmeter.	A = ammeter.
S = switch.	B_1, B_2 = battery terminals.

(*b*) Place 2 litres of water in the vessel, having previously arranged the cells, so that the current and potential difference are as stated above. Arrange the temperature of the water so that it is about 4° C. below the temperature of the room. Test

* An electric incandescent lamp may be used instead of the wire coil. The terminals and leading wires must be carefully insulated so as to prevent short circuiting when the lamp is immersed.

the apparatus for a moment by switching on the current, and see if everything is working satisfactorily.

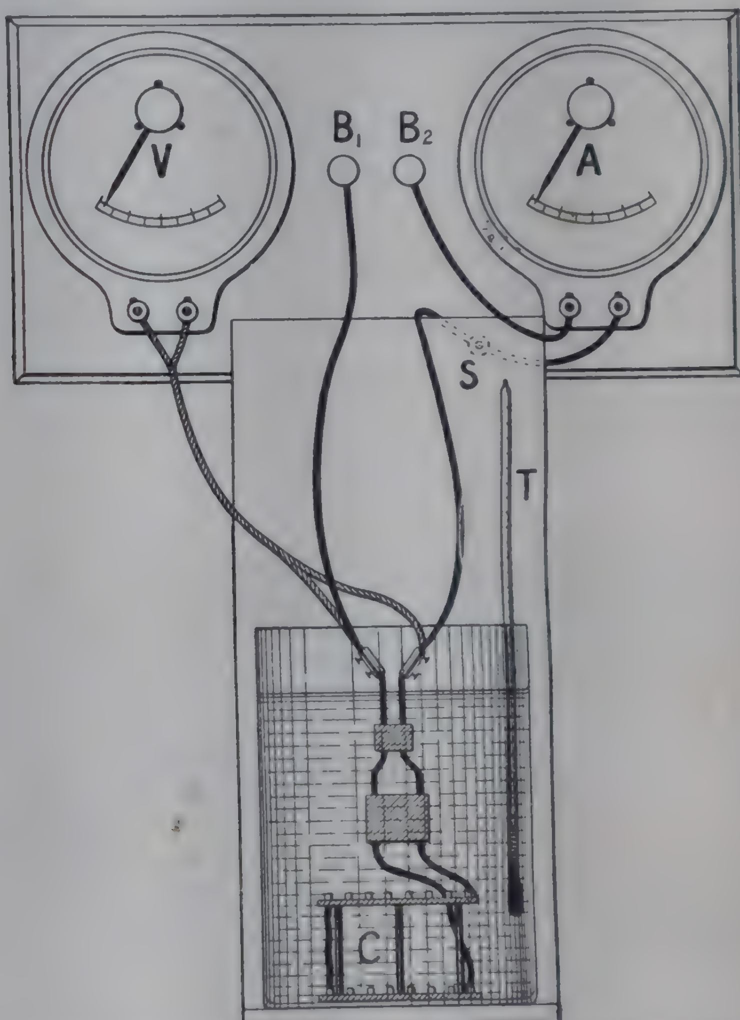

FIG. 92.—Prof. Ayrton's apparatus for the determination of 'J' electrically.

(*c*) Stir the water by moving the coil up and down, being careful not to raise it above the level of the water. Take the initial temperature of the water ($t_1°$) accurately.

(*d*) Switch on the current, at the same time noting the instant of starting by means of a chronometer. Stir well. When the temperature of the water has risen 8°, wait until the next minute (counting from the start) has elapsed, then switch off the current and note the time in seconds (s) during which the experiment has been working. Take continuous readings of the current and potential difference every half minute during the experi-

ment, and find the mean value of each, *i.e.* (V) and (A). Stir well and note the final temperature (t_2).

The electric energy dissipated in the calorimeter

$$=\mathrm{VA}s \times 10^7 \text{ ergs.}$$

The heat equivalent of this energy $= \mathrm{M} \times (t_2 - t_1)$ calories if M is the mass of 2 litres of water at the temperature t_1°.

$$\therefore \text{ Joule's equivalent } \mathrm{J} = \frac{\text{Work done}}{\text{Equivalent heat}} = \frac{\mathrm{VA}s \times 10^7}{\mathrm{M}(t_2 - t_1)}.$$

E.g.

$$\mathrm{M} = 2000 \text{ grams.}$$
$$\mathrm{V} = 8.66.$$
$$\mathrm{A} = 30.$$
$$s = 120.$$
$$t_1^\circ = 12^\circ.94.$$
$$t_2^\circ = 16^\circ.67.$$
$$\mathrm{J} \text{ (calculated)} = 4.18 \times 10^7 \text{ C.G.S. units.}$$

(*e*) From your results calculate the value of J. Repeat the experiment three times, varying the number of cells used, but starting with the same amount of water.

102. Determination of the ratio of the specific heats of air (K) by Clement's and Desormes's method.

For every gas there are two specific heats, viz. :

(1) The specific heat at constant pressure (C_p), *i.e.* the amount of heat required to raise 1 gram of the gas through 1° C. when the pressure remains constant and the volume varies.

(2) The specific heat at constant volume (C_v), *i.e.* the amount of heat required to raise 1 gram of the gas through 1° C. when the volume remains constant and the pressure varies.

The specific heat at constant pressure can be determined by the method of mixtures with a fair amount of ease. The specific heat at constant volume, however, is difficult to determine, but the ratio of the two specific heats $\frac{C_p}{C_v} = \mathrm{K}$ may

be determined by the method given below, and hence $C_v = \frac{C_p}{K}$ can be determined.

Apparatus.—The following modification of Clement's and Desormes's apparatus will be found to give good results (Fig. 93).

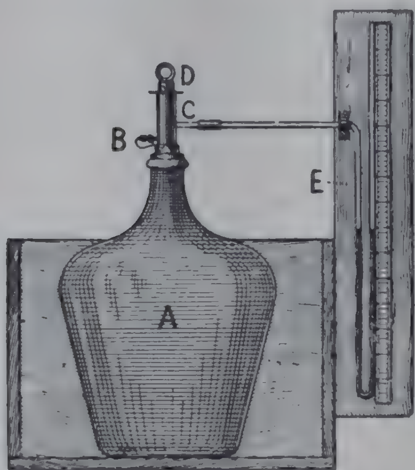

FIG. 93.—Apparatus for the determination of the ratio of the specific heats of air by Clement's and Desormes's method.

The neck of a large carboy A is fitted with a brass tube having a valve D* at the top.

A pneumatic tyre valve B serves to pump in the air during the experiment, while a metal tube C is connected to the manometer E, which is filled with castor oil (specific gravity, 0.95).

The carboy is packed in a cubical box and surrounded with cotton wool or sawdust in order to prevent radiation effects from the experiments. The valve D should be closed by means of a stiff spring and lined with indiarubber to make it perfectly air-tight.

A small quantity of concentrated sulphuric acid is poured into the carboy and serves to dry the air inside.

(*a*) The valve B is connected to a cycle pump and air is forced in until the excess of pressure inside is equal to 40 cm. of oil.

The heat caused by the compression of the air will be gradually dissipated and the manometer reading will gradually decrease and then become steady. At the end of fifteen minutes read off the pressure on the manometer (h_1), and calculate the pressure (P_1) in cms. of water.

If H is the height of the barometer in cms. of mercury, the pressure (P) of the air $= H \times 13.6$ cms. of water and

$$P_1 = (H \times 13.6) + (0.95 \times h_1).$$

(*b*) Now open the valve D so as to allow communication with the atmosphere. At the end of one second close D.

* A hard rubber stopper answers very well for this purpose.

The air in A has expanded adiabatically and is therefore cooler than the outer air while the valve D has been open. As it gradually rises in temperature its pressure increases until the temperature is equal to that of the atmosphere.

After the end of twenty minutes when the manometer reading should be quite constant, read the height h_2 and calculate the pressure P_2

$$=(H \times 13.6)+(0.95 \times h_2).$$

(*c*) Since the ratio $\frac{P}{P_1}$ may be taken as the ratio of the original and final pressures, the ratio $\frac{P}{P_2}$ gives the ratio of the original and final temperatures.

$$\therefore \qquad \left(\frac{P}{P_2}\right)^K = \left(\frac{P}{P_1}\right)^{K-1}.$$

$$K(\log P - \log P_2) = (K-1)(\log P - \log P_1).$$

$$K = \frac{\log P_1 - \log P}{\log P_1 - \log P_2}.$$

E.g.

$$H = 75.7 \text{ cms.}$$

$$\therefore \; P = 75.7 \times 13.6 = \underline{1029.5 \text{ cms.}}$$

$$h_1 = 49.7 \text{ cms.}$$

$$\therefore \; P_1 = (75.7 \times 13.6) + (0.95 \times 49.7)$$

$$= \underline{1077.0 \text{ cms.}}$$

$$h_2 = 12.9 \text{ cms.}$$

$$\therefore \; P_2 = (75.7 \times 13.6) + (0.95 \times 12.9)$$

$$= \underline{1041.8 \text{ cms.}}$$

$$K = \frac{\log 1077 - \log 1029.5}{\log 1077 - \log 1041.8}$$

$$= \underline{1.36.}$$

(*d*) Since P, P_1, P_2 differ only slightly in value

$$K = \frac{P_1 - P}{P_1 - P_2} \text{ approx.}$$

Compare the result obtained by this formula with that obtained in Expt. 102 (*c*).

(*e*) Calculate the value of C_v for air, using the value of (K) obtained in Expt. 102 (*c*) and assuming that $C_p = 0.2372$.

Note.—The value of K found by the above method will be rather lower than the accepted value, viz. 1.402. The value of K for monatomic gases is $\frac{5}{3}$; for polyatomic gases the ratio $\frac{C_p}{C_v} = \frac{5+x}{3+x}$, where x is a quantity depending upon the number of atoms. For a diatomic gas K = 1.40 approximately.

ADDITIONAL NOTES ON CHAPTER XIV.

(1) The following form of simple heat-converting engine is due to Principal E. H. Griffiths (see *Thermal Measurement of Energy*). Take a large glass U-tube about $\frac{1}{2}''$ diameter and $12''$ high, and partially fill it with mercury. Fit a cork at one end of the tube and insert the neck of a glass bulb through the cork. Heat the bulb by means of a Bunsen burner, and notice that the column of mercury will commence to oscillate as a result of the alternate heating and cooling of the mercury in the U-tube.

(2) In Prof. Callendar's apparatus for the determination of 'J' a cylindrical calorimeter of thin brass with its axis horizontal contains a known quantity of water, and is rotated by hand or by electric motor. Unequal weights M and M_1 are suspended from the ends of a silk belt slung over the cylinder and arranged to make one and a half turns round the cylinder. Stability of equilibrium is obtained by the addition of a light spring balance which acts in the opposite direction to the lighter weights. Water is placed in the brass cylinder, and its temperature noted by a thermometer with bent stem.

If m is the spring balance reading

r = radius of the drum,

n = number of turns ;

then work done $= 2\pi nr(M - M_1 + m)g$,

heat produced $= (w_1 s_1 + w_2 s_2)(t_2 - t_1)$,

where w'_1 = weight of liquid in cylinder,

s_1 = specific heat of cylinder,

w_2 = weight of calorimeter,

s_2 = specific heat of calorimeter,

t_1 = initial temperature of liquid,

t_2 = final temperature of liquid ;

$$\therefore\ J = \frac{2\pi nr(M - M_1 + m)g}{(w_1 s_1 + w_2 s_2)(t_2 - t_1)}.$$

Additional Exercises.

1. Determine the value of (J) by an electrical method.

2. Plot a curve showing the relation between the number of revolutions and the temperature of the enclosure in Puluj's apparatus.

3. Measure the ratio of the specific heats of air (K) by Clement's and Desormes's apparatus with the initial pressure (*a*) greater, (*b*) less than the atmospheric pressure.

4. Assuming the value of (K) found in Expt. 102, calculate the velocity of sound in air by means of the formula

$$V = \sqrt{\frac{K.p}{d}}$$

where V = velocity of sound in cms. per sec.

p = pressure of air in dynes

d = density of air in grams per c.c.

5. Find the ratio of the adiabatic and isothermal elasticities of air by Clement and Desormes's method.

(B.Sc. Hons. Lond. 1894.)

6. Find the specific heat of the given liquid by heating it with an electric current. (Int. B.Sc. Pass Lond. 1907.)

7. Find the specific heat of the given liquid with a mechanical equivalent of heat apparatus. (Ext. B.Sc. Hons. Lond. 1908.)

8. Find the mechanical equivalent of heat by the continuous flow calorimeter. (Int. B.Sc. Hons. Lond. 1909.)

9. Find the specific heat of water in work units by means of the given mechanical equivalent of heat apparatus.

(Ext. B.Sc. Hons. Lond. 1909.)

10. Find the specific heat of a liquid by electrical heating.

(Ext. B.Sc. Pass Lond. 1910

11. Find the ratio of the two specific heats of air.

(Int. B.Sc. Pass Lond. 1910

12. Find electrically the specific heat of alcohol, and i variation with temperature over a range of about 15° C. to 60°

(Int. B.Sc. Hons. Lond. 1911

13. Determine the specific heat of a solution of sodiu chloride of three times normal strength by electric heating.

(Ext. B.Sc. Hons. Lond. 1911

14. Determine the value of k and the atomicity of oxyge by means of Clement and Desormes's apparatus. (Fill th apparatus from a cylinder of the compressed gas.)

MISCELLANEOUS EXERCISES.

1. Find the expansion of water between a temperature about that of the room and some temperature above 60° by weighing in it a given solid with a coefficient of expansion 0.000028.

2. Make a thermometer from the given glass tubing, and after determining its scale of comparison with a given thermometer, use it to ascertain the boiling point of the given liquid.

3. Determine the total expansion of water between two chosen temperatures by means of a volume dilatometer. The cubical expansion of glass for $1^\circ = 0.000026$. The density of mercury at $0^\circ = 13.596$, and the coefficient of cubical expansion $= 0.0001815$.

4. Make experiments with a given Boyle's Law apparatus, and plot p against v on paper ruled logarithmically both ways.

5. Find the coefficient of linear expansion with rise of temperature of the given wire.

6. Find the law connecting the pressure and volume of the given gaseous mixture of air and vapour.

7. Find the temperature on the given air thermometer corresponding to 50° on the given mercury thermometer.

8. Repair the given leaky calorimeter, and use it to find the specific heat of lead shot by the addition of warm water.

9. Find the specific heat of the given liquid by dropping in ice. $L = 80$.

10. Make a determination of the heat of combustion of paraffin wax.

11. Find the latent heat of liquefaction and the specific heat of the given specimen of wax.

12. Determine the melting points of the given samples of fusible alloy.

13. Measure by means of a sliding thermo-couple the temperature-fall along the given rod heated at one end and cooled at the other.

14. Construct a differential thermoscope of glass tube and small flasks, and use it to exhibit the relative lowering of temperature by the solution in water of equal quantities of different soluble salts.

15. Plot the thermo-electric power for a range of temperature from 0° to 100° C. of the given pair of metals of which Lead is one.

16. Compare the radiation from a lampblack surface, a white paper surface, and a bright surface at 100°.

17. Determine the law connecting the intensity of heat reflected from a given surface with the angle of incidence.

18. Draw a thermo-electric diagram for the four given metals.

19. Observe the cooling of the given vessel from a temperature 30° or 40° above that of the room, and plot the logarithm of the excess against time on the given paper which is divided logarithmically one way and equally the other.

APPENDIX.

I. PLOTTING CURVES.

Preliminary.—Two quantities, the results of a number of observations or experiments which are so related that any alteration in one produces a corresponding change in the other, can be best represented by a graphical method. By this means it is possible to find by inspection the relation that one variable quantity bears to another.

For this purpose squared paper is used having equidistant vertical and horizontal lines 0.1 inch or 0.1 mm. apart.

The origin of the curve is usually at the bottom left-hand corner, and the lowest horizontal line may be taken as one line of reference or axis and the vertical line as the other axis.

The horizontal line is called the axis of *abscissae*, while the vertical line is called the axis of *ordinates*.

To plot a curve.—Along the line of abscissae one or more squares are taken to represent a unit of one of the two quantities and similarly along the line of ordinates for the representation of the other quantity. The same number of squares need not necessarily represent the same number of units in each case.

A number of points are thus obtained, and by inspection of these points a curved or straight line may be drawn so as to take up an average position among the points.

Example.—To plot a curve showing the relation between the pressure (P) and volume (V) of a gas at constant temperature using the following results (Fig. 94):

P (ordinates) (cms. of mercury).	V (abscissae) c.c.
105.0	7.7
90.8	8.8
77.9	10.2
67.3	12.0
57.3	15.9
52.5	16.5
44.9	18.2
41.5	20.8

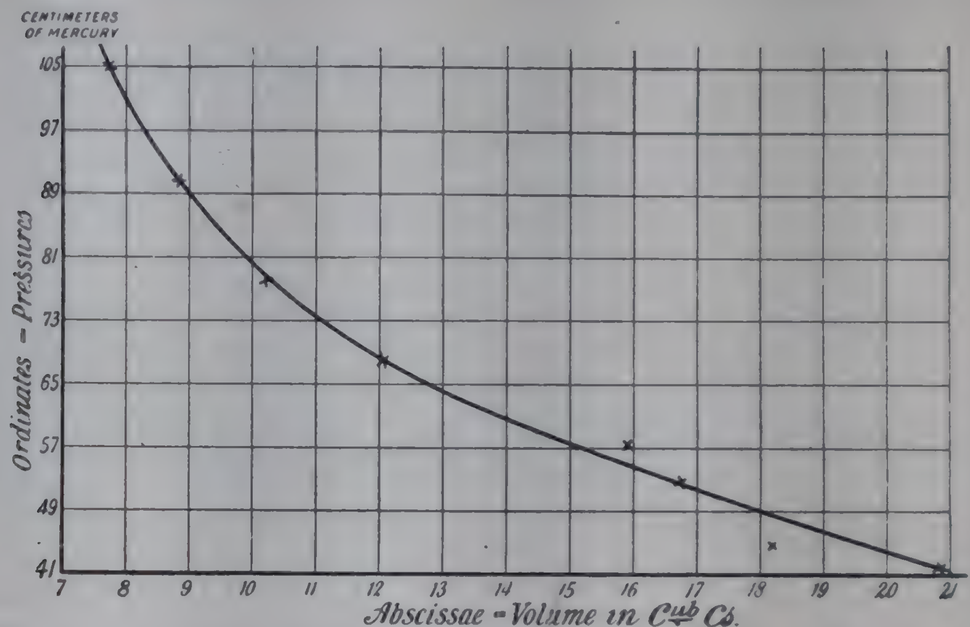

FIG. 94.—Curve to illustrate the relation between the pressure and volume of a gas.

Here starting with the volumes we must plot from 7 to 21 units and we can allow 1 square for 1 c.c.

Along the axis of pressures we must plot from 41 to 105, and we can allow about 1 square for every 8 cms.

The different points are then marked off and a curve drawn through them as in the figure.

EXERCISES.

1. Plot a curve showing the relation between °F. and °C.

F	°C.	°F.	°C.
−40	−40	185	85
5	−15	203	95
32	0	212	100
41	5	221	105
59	15	239	115
77	25	275	135
95	35	284	140
104	40	320	160
131	55	392	200
167	75		

2. Draw a curve showing the relation between the temperature and pressure of water vapour from the following values :

P. (mms. of mercury)	t° C.	P. (mms. of mercury)	t° C.
9.17	10°	906.4	105°
17.4	20°	1491	120°
54.9	40°	2030	130°
117.5	55°	2717	140°
354.6	80°	4651	160°
633.9	95°	9442	190°
760	100°	11690	200°

3. Plot a curve showing the relation between the temperature of a calorimeter and the time.

Time in minutes.	Temperature. °C.	Time in minutes.	Temperature. °C.
1	16.7	7	36.5
2	24.0	8	36.1
3	31.4	9	35.7
4	36.1	10	35.5
5	37.0	11	35.4
6	37.0	12	35.2

II. USE OF LOGARITHMS AND LOGARITHM TABLES.

Logarithms are of great service in saving labour in the calculation of the results of experiments.

Logarithms consist of an integral part called the *index* or *characteristic* and a decimal portion called the *mantissa.*

In Table 23 the mantissa is given of any number containing not more than four significant figures.

The characteristic portion of any logarithm can always be inserted by inspection.

The rules for finding the characteristic are as follows:

(1) For any number greater than unity the characteristic is positive

and is less by one than the number of figures to the left of the decimal point.

(2) For any number less than unity the characteristic is negative and is one more than the number of zeros following the decimal point.

Example.—To find log 123.2.

Looking up the number 123.2 in the log Table we find the mantissa is 0916;

$$\therefore \text{ the log is } 2.0916,$$

since there are three figures to the left of the decimal point.

Again, to find log 0.0542.

Looking up the significant figure 542 in the log Tables we find the mantissa is 7340;

$$\therefore \log 0.0542 = \bar{2}.7340.$$

N.B.—In this case the mantissa only is positive and the characteristic is negative.

Again, $\log 2 = 0.3010.$

We look up in the Tables for log 20 since the logs of 2 and 20 have the same mantissa.

Rules of logarithms.

(1) *The logarithm of a product of two numbers is equal to the sum of the logs of the two factors*, or $\log ab = \log a + \log b$.

E.g.

$$\begin{aligned} \log(23.12 \times 1.416) &= \log 23.12 + \log 1.416 \\ &= 1.3640 + 0.1510 \\ &= 1.5150. \end{aligned}$$

Referring to the antilogarithms (Table, p. 209) we find that 3273 is the number whose logarithm has a mantissa of .5150;

$$\therefore \text{ antilog of } 1.5150 = 32.73;$$

$$\therefore 23.12 \times 1.416 = \underline{32.73}.$$

(2) The logarithm of the quotient of two numbers is equal to the difference of the logarithms of the numerator and denominator or

$$\log a/b = \log a - \log b.$$

E.g.

$$\begin{aligned} \text{(i.) } \log \frac{214.6}{0.0041} &= \log 214.6 - \log 0.0041 \\ &= 2.3316 - \bar{3}.6128 \\ & \underline{\bar{3}.6128} \\ &= \underline{4.7188} \end{aligned}$$

In subtracting 6 from 3 giving 7 and +1 to carry, we add +1 to $\bar{3}$ giving $\bar{2}$ and then subtract $\bar{2}$ from 2 giving 4.

The antilog of 4.7188 = $\underline{52340}$, the 0 being added to make up the requisite number of figures.

(ii.) The value of $\frac{32.1 \times .00469 \times 1279}{1.99 \times 8147} = \frac{a}{b}$ is worked thus:

$$\begin{aligned} \log\ 32.1 &= 1.5065 \\ \log 0.00469 &= \bar{3}.6712 \\ \log\ 1279 &= \underline{3.1069} \\ \therefore\ \log a &= 2.2846 \\ \log b &= \underline{4.2099} \\ \log \frac{a}{b} &= \underline{\bar{2}.0747} \end{aligned} \qquad \begin{aligned} \log 1.99 &= 0.2989 \\ 8147 &= \underline{3.9110} \\ \therefore\ \log b &= \underline{4.2099} \end{aligned}$$

$$\therefore\ \frac{a}{b} = \underline{0.01188}$$

(3) The logarithm of a power is the product of the logarithm of the number by the index of the power;

$$\text{or } \log a^n = n \times \log a.$$

Also
$$\log \sqrt[n]{a} = \log a^{\frac{1}{n}} = \frac{1}{n} \times \log a.$$

E.g. (i.) $\log (0.005126)^3$

$$= 3 \log 0.005126$$
$$= 3 \times (\bar{3}.7098) = \bar{7}.1294.$$

antilog = 0.0000001347

$\therefore\ (0.005126)^3 = \underline{0.0000001347}.$

(ii.) $\log \sqrt[4]{0.01593}$

$$= \frac{1}{4} \log 0.01593$$

$$= \frac{1}{4} (\bar{2}.2022)$$

$$= \frac{1}{4} (\bar{4} + 2.2022) \quad \text{(adding } \bar{2} \text{ to characteristic and } +2 \text{ to mantissa.)}$$

$$= \bar{1}.5506,$$

antilog = 0.3553

$$\therefore\ \sqrt[4]{0.01593} = \underline{0.3553}$$

$$\text{(iii.)}\quad \frac{(4.06)^3 \times \sqrt[4]{9.117} \times 0.00076}{64.35 \times \sqrt{0.015}} = \frac{a}{b}$$

$$\log (4.06)^3 = 3(.6085) \quad . \quad . \quad . \quad . \quad . = 1.8255$$

$$\log \sqrt[4]{9.117} = \frac{1}{4}(.9598) \quad . \quad . \quad . \quad . \quad . = 0.2399$$

$$\log 0.00076 \quad . \quad . \quad . \quad . \quad . \quad . \quad . = \bar{4}.8808$$

$$\log a = \bar{2}.9462$$

$$\log 64.35 \quad . \quad . \quad . \quad . \quad . \quad . \quad . = 1.8085$$

$$\log \sqrt{0.015} = \frac{1}{2}(\bar{2}.1761) \quad . \quad . \quad . \quad . \quad . = \bar{1}.0881$$

$$\log b = .8966$$

$$\log a = \bar{2}.9462$$

$$\log b = .8966$$

$$\log \frac{a}{b} = \bar{2}.0496$$

$$\therefore \frac{a}{b} = 0.01121$$

TABLES OF PHYSICAL CONSTANTS, ETC.

I. Conversion Tables.

1 cm.	= 0.3937	inch.	1 inch	= 2.54	cms.
1 sq. cm.	= 0.155	sq. inch.	1 sq. in.	= 6.45	sq. cms.
1 c.c.	= 0.061	c. inch.	1 c. in.	= 16.386	c.c.
1 gram	= 15.432	grains.	1 grain	= 0.065	gram.
1 kilogram	= 2.205	lbs.	1 lb.	= 435.6	grams.

1 oz. avoir. = 28.35 grams.
1 oz. troy = 31.10 grams.

$$\ldots^\circ \text{F.} = \frac{9}{5} \ldots^\circ \text{C.} + 32$$

$$\ldots^\circ \text{C.} = \frac{5}{9} (\ldots^\circ \text{F.} - 32).$$

II. Atomic Weights.

Hydrogen, H	= 1.	Copper, Cu	= 63.2
Carbon, C	= 12.0	Zinc, Zn	= 65.1
Nitrogen, N	= 14.0	Silver, Ag	= 107.7
Oxygen, O	= 15.96	Tin, Sn	= 118.7
Sodium, Na	= 23.0	Antimony, Sb	= 119.7
Magnesium, Mg	= 24.3	Iodine, I	= 126.5
Sulphur, S	= 32.0	Platinum, Pt	= 194.5
Chlorine, Cl	= 35.4	Mercury, Hg	= 199.6
Potassium, K	= 39.0	Lead, Pb	= 206.4
Calcium, Ca	= 39.9	Bismuth, Bi	= 208.4
Iron, Fe	= 55.9		

III. Densities.

Solids.

Mercury,	13.56 (15° C.)	Lead,	11.37
Copper,	8.93	Silver,	10.5
Brass,	8.4–8.7	Tin,	7.29
Iron,	7.86	Steel,	7.7–7.9
Glass, flint,	2.9–4.5	Silica,	2.07–2.21
,, crown,	2.4–2.6		
,, Jena,	3.2–4.0	Ice,	0.916
Aluminium,	2.65	Wax, paraffin,	0.88–0.93
Quartz,	2.66	,, bees,	0.96

Liquids.

Glycerine,	1.26	Ether,	0.72
Aniline,	1.02	Methylated spirit,	0.83
Benzene,	0.88	Petrol,	0.68–0.72
Turpentine,	0.87	Oil, castor,	0.97
Alcohol, ethyl,	0.79	,, olive,	0.92
,, methyl,	0.80	,, paraffin,	0.80

Gases at 0° C. and 760 mm. pressure.

Carbonic acid,	0.00197	Nitrogen,	0.00125
Oxygen,	0.00143	Hydrogen,	0.0000899
Air,	0.001293		

IV. Correction for temperature of mercury in thermometer stem.

$T = t + .000143\,n(t - t')$ on Centigrade scale,

where T = corrected temperature,

t = observed temperature,

t' = mean temperature of glass stem and mercury column,

n = length of mercury in stem in scale degrees.

Values of $.000143\,n(t - t')$

n.	$t - t'$.							
	10°	20°	30°	40°	50°	60°	70°	80°
10°	.01	.03	.04	.06	.07	.09	.10	.11
20°	.03	.06	.09	.11	.14	.17	.20	.23
30°	.04	.09	.13	.17	.21	.26	.30	.34
40°	.06	.11	.17	.23	.29	.34	.40	.46
50°	.07	.14	.21	.29	.36	.43	.50	.57
60°	.09	.17	.26	.34	.43	.51	.60	.69
70°	.10	.20	.30	.40	.50	.60	.70	.80
80°	.11	.23	.34	.46	.57	.69	.80	.92
90°	.13	.26	.39	.51	.64	.77	.90	1.03
100°	.14	.29	.43	.57	.72	.86	1.00	1.14

V. Volume and density of water at different temperatures.

$t°$.	Volume of unit mass.	Density.	$t°$.	Volume of unit mass.	Density.
0°	1.0001	.9999	55°	1.0144	.9858
4°	1.0000	1.0000	60°	1.0170	.9834
10°	1.0003	.9997	65°	1.0197	.9807
15°	1.0009	.9991	70°	1.0226	.9780
20°	1.0018	.9982	75°	1.0257	.9750
25°	1.0029	.9971	80°	1.0289	.9720
30°	1.0044	.9957	85°	1.0322	.9688
35°	1.0059	.9941	90°	1.0357	.9656
40°	1.0077	.9924	95°	1.0394	.9621
45°	1.0097	.9903	100°	1.0433	.9587
50°	1.0120	.9882			

VI. Volume of mercury at different temperatures.

t.	V.	D.	t.	V.	D.
0°	1.0000	13.596	60°	1.0108	13.450
10°	1.0018	13.572	70°	1.0127	13.426
20°	1.0036	13.547	80°	1.0145	13.401
30°	1.0054	13.523	90°	1 0163	13.377
40°	1.0072	13.499	100°	1.0182	13.303
50°	1.0090	13.474			

VII. Coefficients of expansion (absolute).

Solids.

Aluminium,	0.000025	Bronze,	0.0000177
Copper,	0.0000167	Glass, soft,	0.0000085
Iron, cast,	0.000010	,, hard,	0.0000097
,, wrought,	0.000012	,, Jena,	0.0000078
Steel,	0.0000105–116	Ice, $-10°$ C. to $0°$ C.,	0.0000507
Platinum,	0.0000089	Silica,	0.00000051
Tin,	0.000021		
Brass,	0.0000189		

Liquids.

Alcohol, ethyl,	0.00110	Oil, olive,	0.00071
,, methyl,	0.00122	,, paraffin,	0.00090
Aniline,	0.00085–0.00095	Turpentine,	0.00094–0.00105
Benzene,	0.00124	Mercury,	0.000181
Glycerine,	0.00051	Water,	0.000476

Gases.

Air (const. pressure), . . . 0.00367

VIII. Specific heats.

Solids.

Aluminium,	15°–185°	0.219	Zinc,	20°–100°	0.093
Carbon, graphite,	11°	0.60	Brass,	0°–100°	0.094
,, diamond,	11°	0.113	Glass, crown,	10°–50°	0.16
Copper,	20°–100°	0.094	,, flint,	10°–50°	0.12
Iron,	20°–100°	0.119	Ice,	$-20°$ to $-1°$	0.502
Lead,	20°–100°	0.031	Marble,	18°	0.21
Platinum,	18°–100°	0.032	Paraffin wax,	0°–20°	0.69
Tin,	19°–100°	0.055	Quartz,	15°	0.189

Liquids.

Alcohol, ethyl,	40°	0.648	Oil, olive,	10°	0.47
,, methyl,	12°	0.601	,, paraffin,	20°–60°	0.53
Aniline,	15°	0.514	,, castor,	15°	0.44
Benzene,	40°	0.423	Turpentine,	18°–40°	0.42–0.45
Glycerine,	18°–50°	0.58	Mercury,	40°	0.033

Gases.

Air (con. press.),	20°–100°	0.2372	Ammonia (con. press.),	23°–100°	0.520
Hydrogen ,,	,,	3.402	Air (const. vol.),	0°	0.1715
Oxygen ,,	20°–44°	0.242	Hydrogen ,,	50°	2.402
Nitrogen ,,	0°	0.235	Nitrogen ,,	0°	0.175

Ratio of specific heats for gases ('K').

Air,	0°	1.402	Oxygen,	5°–14°	1.400
Hydrogen,	4°–16°	1.409	CO_2,	4°–11°	1.30
Nitrogen,		1.400	NH_3,	,,	1.34
Helium,	0°	1.630	Argon,	0°	1.667

Specific heat of water.

Temperature.	Specific heat.	Temperature.	Specific heat.
10°	1.0027	60°	1.0000
20°	1.0000*	70°	1.0016
30°	0.9987	80°	1.0033
40°	0.9982	90°	1.0053
50°	0.9987		

* 4.180 Joules.

Specific heat of aniline.

Temperature.	Specific heat.	Temperature.	Specific heat.
15°	0.5137	35°	0.5222
20°	0.5155	40°	0.5244
25°	0.5175	45°	0.5268
30°	0.5198	50°	0.5294

Specific heat of copper at $t^\circ = 0.0901 + 0.0000646t$.
,, iron ,, $= 0.1060 + 0.00014t$.
,, zinc ,, $= 0.0901 + 0.000075t$.

Specific heat of 15 % solution $NH_4Cl = 0.84$.
,, 15 % ,, $CaCl_2 = 0.78$.
,, 20 % ,, $NaCl = 0.82$.

IX. Latent heat of fusion.

Substance.	Melting point.	Latent heat.
Ice, ...	0°	79.77
Benzene, . . .	5°.3	30.0
Acetic acid, . .	17°	43.1
Nitro-benzene, . .	6°	22.4
Naphthalene, . .	80°	35
Paraffin wax, . .	52°	35.1
Bees wax, . .	62°	42.3

X. Latent heat of vaporisation.

Substance.	Boiling point.	Latent heat.
Alcohol, ethyl,	78°.1	207
,, methyl,	64°.5	267
Aniline,	184°	93.1
Acetone,	56°.3	125
Benzene,	80°.1	95
Ether,	34°.9	84
Turpentine,	159°	70
Water,	100°	539
Toluene,	111°	84

XI. Melting point of metals, alloys, and fats.

Antimony,	630°
Cadmium,	321°
Bismuth,	269°
Lead,	326°
Tin,	232°
Zinc,	418°

Britannia metal,	236°
Rose's alloy,	99°
Wood's alloy,	76°

Butter,	28°–33°
Lard,	36°–40°
Bees wax,	61°–64°
Naphthalene,	80°
Paraffin wax, soft,	38°–52°
,, hard,	52°–56°

XII. Maximum vapour pressure of water vapour.

$t°$ C.	Pressure (mms.).	$t°$ C.	Pressure (mms.).	$t°$ C.	Pressure (mms.).
0°	4.58	16°	13.62	60°	149.2
1°	4.92	17°	14.52	65°	187.5
2°	5.29	18°	15.46	70°	233.5
3°	5.68	19°	16.46	75°	289.2
4°	6.10	20°	17.51	80°	355.1
5°	6.54	21°	18.62	85°	433.8
6°	7.01	22°	19.79	90°	525.8
7°	7.51	23°	21.02	95°	634.3
8°	8.04	24°	22.32	100°	760.0
9°	8.61	25°	23.69	105°	906.5
10°	9.20	30°	31.71	110°	1074
11°	9.84	35°	42.02	115°	1269
12°	10.51	40°	55.13	120°	1489
13°	11.23	45°	71.79	130°	2026
14°	11.98	50°	92.30	140°	2709
15°	12.78	55°	117.9	150°	3569

XIII. Boiling point of water at different pressures.

Press. (mms.).	Boiling Point.	Press. (mms.).	Boiling Point.	Press. (mms.).	Boiling Point.	Press. (mms.).	Boiling Point.
740	99°.256	750	99°.630	760	100°.000	770	100°.366
1	.293	1	.667	1	.037	1	.402
2	.331	2	.704	2	.074	2	.439
3	.368	3	.741	3	.110	3	.475
4	.406	4	.778	4	.147	4	.511
5	.443	5	.815	5	.184	5	.548
6	.481	6	.852	6	.220	6	.584
7	.518	7	.889	7	.257	7	.620
8	.555	8	.926	8	.293	8	.656
9	.593	9	.963	9	.330	9	.692
750	99°.630	760	100°.000	770	100°.366	780	100°.728

XIV. Depression of freezing point of solutions.

	Freezing Point.	Mol. Depression.
Acetic acid, . . .	16°.9	39
Naphthalene, . . .	80°	70
Phenol, ...	40°	73
Benzene, . .	5°.5	51
Water {for most organic substances,}	0°	18.5
Water {for NaCl, NH_4Cl, KCl,}	0°	35
Nitro-benzene, . .	6°	70
Aniline, ...	−6°	59

XV. Rise of boiling point of solutions.

	Boiling Point.	Mol. Rise.
Aniline, ...	184° C.	32.2
Water, ...	100°	5.2
Benzene, . . .	80°.1	26.1
Ethyl alcohol, . .	78°.1	11.5

XVI. Maximum pressure of mercury vapour.

$t°$ C.	Pressure (mms.).	$t°$ C.	Pressure (mms.).
0°	0.00016	80°	0.0885
10°	0.00043	100°	0.276
20°	0.00109	150°	2.88
30°	0.00257	200°	17.81
40°	0.00574	300°	249.0
50°	0.0122	357°	760.0
60°	0.0246		

XVII. Thermal conductivities.

The coefficient (k) is the quantity of heat in calories which is transmitted per second through a plate one centimetre thick per square centimetre of its area when the difference of temperature between the two faces of the plate is 1° C.

Substance.		k.	Substance.		k.
Aluminium,	18°	0.504	Hydrogen,	0°	0.000318
Brass, .	17°	0.260		100°	0.000369
Copper, pure,	18°	0.918	Nitrogen, .	0°	0.000052
	100°	0.908	Air, . .	0°	0.000052
Iron, wrought,	18°	0.144	Oxygen, .	0°	0.000056
	100°	0.143	Ammonia, .	0°	0.000046
Iron, cast,	30°	0.149	Carbon dioxide,	0°	0.000032
	100°	0.110			
Steel,	18°	0.108	Glass, crown, .		0.0025
	100°	0.107	,, flint, . .		0.0020
Nickel,	18°	0.142	Wood, oak, . .		0.0006
	100°	0.138	,, pine, .		0.0004
Mercury, .	17°	0.0197	Asbestos paper, .		0.0006
Tin,	18°	0.155	Cotton, . .		0.00055
	100°	0.145	Cotton wool, .		0.00004
Zinc,	18°	0.265	Cork, . . .		0.00013
	100°	0.262	Flannel, . .		0.00023
			Marble, . .		0.0071
Water,	4°	0.00138	Paper, . . .		0.0003
	20°	0.00143	Rubber, . .		0.00045
Ethyl alcohol,	25°	0.00043	Sawdust, . .		0.00012
Aniline, .	12°	0.00041	Silk, . . .		0.00022
Glycerine, .	25°	0.00068	Slate, . . .		0.0047
Turpentine, .	13°	0.00031			
Olive oil, .	15°	0.00039			

XVIII. Emissive powers.

White lead, . . .	100	Mica, ...	80
Lampblack, . . .	100	Tin, ...	12
Paper, ...	98	Copper, ...	12
Crown glass, . . .	90	Polished brass, . . .	11

XIX. Diathermancies.

Substance.	Source of heat.	
	Locatelli Lamp.	Glowing platinum spiral.
Rocksalt, . .	92 per cent.	92 per cent.
Calcspar, . .	39 ,,	28 ,,
Glass, . . .	39 ,,	24 ,,
Alum, . . .	9 ,,	2 ,,

(Thickness of plate, 2.6 mm.)

XX. Absorptive powers.

Substance.	Locatelli Lamp.	Glowing platinum spiral.	Hot water (100°).
Lampblack,	100	100	100
White lead,	96	95	100
Shellac,	48	47	72
Metals, .	14	13·5	13

Air, ...	1
Chlorine, ...	39
Carbonic acid gas, . . .	90
Ammonia, ...	1195

XXI. Reflective powers.

Silver, ... 97
Tin, ... 85
Platinum, ...
Iron, ...

XXII. Refractive indices.

Water (D line), . . 1.333
Alcohol, . . . 1.364
Crown glass, . . 1.565
Flint glass, . . . 1.6
Quartz, . . . 1.5

XXIII. Heat in calories, evolved on burning 1 gram of

Coke,		6900-7100
Coal	Bituminous,	7400-8500
	Anthracite,	7800
	Lignite,	6900

XXIV. Heat in British thermal units evolved on burning one cubic foot of

Producer gas (Siemens),	891
Coal gas,	680
Water gas,	347

XXV. Solubilities of solids in water.

Number of grams of anhydrous substances which when dissolved in 100 grams of water make a saturated solution at the temperature stated.

Substance.	0°.	20°.	40°.	60°.	80°.	100°.
Am. chloride, NH_4Cl,	29.4	37.2	45.8	55.2	65.6	77.3
Copper sulphate, $CuSO_4, 5H_2O$,	14.3	20.7	28.5	40.0	55.0	75.0
Potassium chloride, KCl,	27.6	34.0	40.0	45.5	51.1	56.7
Potassium nitrate, KNO_3,	13.3	32	64	110	169	246
Sodium chloride, $NaCl$,	35.7	36	36.6	37	38	39.0
Sodium sulphate, $Na_2SO_4, 10H_2O$,	5.0	19.4	49	45	44	42

XXVI. Molecular heat of formation (H.F.) in gram calories per gram molecule of compound.

Compound.	Mol. H.F.	Compound.	Mol. H.F.	Compound.	Mol. H.F.
Non-metals.	$\times 10^3$.	Metals.	$\times 10^3$.		$\times 10^3$.
HCl, gas, .	22.0	NH_4Cl, .	76.3	$MgSO_4$, .	302
,, Aq, .	39.3	,, Aq, .	72.4	,, Aq,	322
H_2O, liquid,	68.4	NH_4OH, Aq, .	90	KCl, .	106
,, gas, .	58.1			,, Aq,	101.6
NH_3, .	12	$CaCl_2$, .	170	KNO_3, .	119
CO, amorphous carbon,	29	,, Aq,	187.4	NaCl, .	97.8
		$CaSO_4$, .	318	Na_2SO_4, .	328
		$Ca(NO_3)_2$, .	202	Na_2CO_3,	272
CO_2, amorphous carbon,	97.3	$CuSO_4$, .	183	$ZnSO_4$, .	230
		,, Aq,	198.8	,, Aq,	249
		$Pb(NO_3)_2$, .	105.5	NaOH,	102.3
H_2SO_4, liquid, .	193	,, Aq,	97.9	,, Aq,	112.2
H_2SO_4, Aq,	210				
HNO_3, liquid, .	41.6				
HNO_3, Aq,	49				

Note.—The H.F. of $CuSO_4Aq = 198800$; H.F. of $CuSO_4 = 183000$. $\therefore$ heat of solution of $CuSO_4 = 15800$ cals. per gram molecule.

XXVII. Molecular heat of neutralisation in gram calories per gram molecule of bases, e.g.

$$NH_4OH \,.\, Aq + HCl \,.\, Aq = NH_4Cl \,.\, Aq + H_2O + 12300 \text{ cals.}$$

Base.	HCl.	HNO_3.	$\frac{1}{2}H_2SO_4$.	$\frac{1}{2}H_2CO_3$.
1 NaOH, . .	13.7	13.6	15.64	10.1
1 KOH, . .	13.7	13.8	15.7	10.1
1 NH_4OH, . .	12.3	12.3	14.3	8.4
$\frac{1}{2}$CaOH, . .	14.0	13.9	15.6	9.5
$\frac{1}{2}Mg(OH)_2$, . .	13.8	13.8	15.3	9.0
$\frac{1}{2}$BaOH, . .	13.9	14.0	18.4	11.0

XXVIII. Heat of combustion (H.C.) and formation (H.F.) of carbon compounds in gram calories per gram molecule.

Compound.	H.C.	H.F.
	$\times 10^3$.	$\times 10^3$.
Methane, CH_4,	212	21.7
Ethane, C_2H_6,	371	28.6
Acetylene, C_2H_2,	312	−47.8
Ethylene, C_2H_4,	333	− 2.7
Benzene, C_6H_6,	799	−12.5
Naphthalene, $C_{10}H_8$,	1239	
Toluene, C_7H_8,	956	− 3.5
Ethyl alcohol, C_2H_6O,	340	58.5
Ethyl ether, $C_4H_{10}O$,	660	70
Carbon bisulphide, CS_2,	265	−26
Aniline, C_6H_7N,	838	−17.4

XXIX. Molecular heat of dilution, i.e. heat evolved on diluting a gram molecule of liquid with water. The heat of dilution of $2NaCl, nH_2O$ ($n = 20$) to ($2NaCl, 100H_2O$) absorbs 2×1060 cals. per gram molecule.

HCl. $n = 0$.		HNO_3. $n = 0$.		H_2SO_4. $n = 0$.		NaOH. $n = 3$.	
H_2O.	$\times 10^3$.	H_2O.	$\times 10^3$.	H_2O.	$\times 10^3$.	H_2O.	$\times 10^3$.
1	5.37	1	3.28	1	6.38	5	2.1
2	11.36	5	6.6	5	13.1	9	3.1
5	14.96	10	7.32	50	16.7	25	3.26
50	17.1	20	7.46	200	17.1	200	2.94
300	17.3	320	7.49				

2NaCl. $n = 20$.		$2NaNO_3$. $n = 12$.		Na_2SO_4. $n = 50$.	
H_2O.	$\times 10^3$.	H_2O.	$\times 10^3$.	H_2O.	$\times 10^3$.
100	−1.06	50	−2.26	100	−0.66
200	−1.31	100	−3.29	200	−1.13
400	−1.41	200	−3.86	400	−1.38
		400	−4.19	800	−1.48

XXX. Mathematical Tables.

LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

LOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8459	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	5	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	2	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	[illegible]
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	[illegible]
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	[illegible]
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	[illegible]
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	[illegible]
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	[illegible]
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	[illegible]
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	[illegible]
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	[illegible]
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	[illegible]
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	[illegible]
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	[illegible]
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	[illegible]
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	[illegible]

ANTILOGARITHMS.

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	7	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

TRIGONOMETRICAL RATIOS.

Angle.	Radians.	Sine.	Tangent.	Cotangent.	Cosine.		
0°	0	0	0	∞	1	1·5708	90°
1	·0175	·0175	·0175	57·2900	·9998	1·5533	89
2	·0349	·0349	·0349	28·6363	·9994	1·5359	88
3	·0524	·0523	·0524	19·0811	·9986	1·5184	87
4	0698	·0698	·0699	14·3006	·9976	1·5010	86
5	·0873	·0872	·0875	11·4301	·9962	1·4835	85
6	·1047	·1045	·1051	9·5144	·9945	1·4661	84
7	·1222	·1219	·1228	8·1443	·9925	1·4486	83
8	·1396	·1392	·1405	7·1154	·9903	1·4312	82
9	·1571	·1564	·1584	6·3138	·9877	1·4137	81
10	·1745	·1736	·1763	5·6713	·9848	1·3963	80
11	·1920	·1908	·1944	5·1446	·9816	1·3788	79
12	·2094	·2079	·2126	4·7046	·9781	1·3614	78
13	·2269	·2250	·2309	4·3315	·9744	1·3439	77
14	·2443	·2419	·2493	4·0108	·9703	1·3265	76
15	·2618	·2588	·2679	3·7321	·9659	1·3090	75
16	·2793	·2756	·2867	3·4874	·9613	1·2915	74
17	·2967	·2924	·3057	3·2709	·9563	1·2741	73
18	·3142	·3090	·3249	3·0777	·9511	1·2566	72
19	·3316	·3256	·3443	2·9042	·9455	1·2392	71
20	·3491	·3420	·3640	2·7475	·9397	1·2217	70
21	·3665	·3584	·3839	2·6051	·9336	1·2043	69
22	·3840	·3746	·4040	2·4751	·9272	1·1868	68
23	·4014	·3907	·4245	2·3559	·9205	1·1694	67
24	·4189	·4067	·4452	2·2460	·9135	1·1519	66
25	·4363	·4226	·4663	2·1445	·9063	1·1345	65
26	·4538	·4384	·4877	2·0503	·8988	1·1170	64
27	·4712	·4540	·5095	1·9626	·8910	1·0996	63
28	·4887	·4695	·5317	1·8807	·8830	1·0821	62
29	·5061	·4848	·5543	1·8040	·8746	1·0647	61
30	·5236	·5000	·5774	1·7321	·8660	1·0472	60
31	·5411	·5150	·6009	1·6643	·8572	1·0297	59
32	·5585	·5299	·6249	1·6003	·8480	1·0123	58
33	·5760	·5446	·6494	1·5399	·8387	·9948	57
34	·5934	·5592	·6745	1·4826	·8290	·9774	56
35	·6109	·5736	·7002	1·4281	·8192	·9599	55
36	·6283	·5878	·7265	1·3764	·8090	·9425	54
37	·6458	·6018	·7536	1·3270	·7986	·9250	53
38	·6632	·6157	·7813	1·2799	·7880	·9076	52
39	·6807	·6293	·8098	1·2349	·7771	·8901	51
40	·6981	·6428	·8391	1·1918	·7660	·8727	50
41	·7156	·6561	·8693	1·1504	·7547	·8552	49
42	·7330	·6691	·9004	1·1106	·7431	·8378	48
43	·7505	·6820	·9325	1·0724	·7314	·8203	47
44	·7679	·6947	·9657	1·0355	·7193	·8029	46
45	·7854	·7071	1·0000	1·0000	·7071	·7854	45
		Cosine.	Cotangent.	Tangent.	Sine.	Radians.	Angle.

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(Names of persons are printed in italics. The numbers refer to pages.)

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